APPENDIX.

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Washington, R.	Pay Inspector
Watson, E. W.	Lieutenant
Weaver, W. D.	Asst. Engineer
Webb, T. E.	Naval Constructor
Webster, E. B.	Asst. Paymaster
Welles, R.	Naval Cadet
Wells, C. H.	Commodore
Wells, H.	P. Asst. Surgeon
West, C. H.	Lieutenant
White, E.	Lieut.-Commander
White, U. S. G.	Civil-Engineer
Whitham, J. M.	Asst. Engineer
Wilner, F. A.	Lieutenant.
Wilson, Byron	Captain
Wilson, F. A.	Chief-Engineer
Wilson, J. C.	Lieutenant
Wilson, T. D.	Chief-Constructor
Windsor, W. A.	P. Asst. Engineer
Winn, J. K.	Lieut.-Commander
Winslow, F.	Lieutenant
Winterhalter, A. G.	Ensign
Wirt, W. E.	Naval Cadet
Wise, F. M.	Lieutenant
Wood, E. P.	Lieutenant
Wood, S. S.	Naval Cadet
Wood, W. M.	Lieutenant
Woodbridge, W. E.	Washington
Woodward, J. J.	Asst. Naval Const'r
Woolverton, T.	Surgeon
Wooster, L. W.	P. Asst. Engineer
Worden, J. L.	Rear-Admiral
Worthington, W. F.	Asst. Engineer
Wright, M. F.	Lieutenant
Wright, R. K.	Ensign
Yates, A. R.	Commander
Yates, I. I., Esq.	Schenectady
Young, J. M. T.,	1st Lt. U.S.M.C.
Zane, A. V.	P. Asst. Engineer

LIFE MEMBERS—36.

Brown, A. D.,	Commander.	Prize Essayist, 1879.
Belknap, C.,	Lieutenant.	Prize Essayist, 1880.
Very, E. W.,	Lieutenant.	Prize Essayist, 1881.
Kelley, J. D. J.,	Lieutenant.	Prize Essayist, 1882.
Calkins, C. G.,	Lieutenant.	Prize Essayist, 1883.

Allen, R. W.	Paymaster
Barker, A. S.	Commander
Bixby, W. H,	Captain U. S. A.
Coryell, M., Esq.,	New York
Delamater, C. H., Esq.	New York
Evans, E. T., Esq.	Buffalo
Fletcher, A., Esq.	New York
Forbes, R. B., Hon.	Milton, Mass.
Gardner, H. W., Esq.	Providence
Gorringe, H. H., Esq.	Philadelphia
Hanford, F.	Lieutenant
Hicks, B. D.	Old Westbury, N. Y.
Keim, G. De B., Esq.	Philadelphia
Leary, J. D., Esq.	Brooklyn
Mason, T. B. M.	Lieutenant
Moore, J. H.	Lieutenant
Palmer, N. F., Jr.	New York
Phœnix, Lloyd, Esq.	New York
Pond, C. F.	Ensign
Quintard, G. W., Esq.	New York
Roach, John, Esq.	Chester, Pa.
Rowland, T. F., Esq.	Brooklyn

Slack, W. H., Esq. Washington
Steers, H., Esq. New York
Tanner, Z. L. Lieut.-Commander
Thomas, C. M. Lieut.-Commander
Thurston, R. H., Prof. Hoboken, N.J.
Ubsdell, J. A., Esq. Port Eads, La.
Ward, Aaron Lieutenant
Watrous, Chas., Esq. New York
Weed, G. E., Esq. New York

HONORARY MEMBERS—9.

Arranged in order of Election.

Hon. W. E. Chandler (ex-officio).
Chief-Justice C. P. Daly.
President C. W. Eliot, LL. D.
Captain J. Ericsson.
General U. S. Grant.
Professor J. E. Hilgard.
John D. Jones, Esq.
Lieutenant Alfred Collet.
President D. C. Gilman, LL. D.

ASSOCIATE MEMBERS—58.

Abbot, F. V. 1st Lieut. U. S. A.
Acland, W. A. D. Commander R. N.
Angstrom, A., C. E. Torpedo Stat'n
Batten, A. W. C. Lieutenant R. N.
Bessels, E., M. D. Washington
Bogert, J. L., Esq. Flushing, N.Y.
Bole, J. K., Esq. Cleveland, O.
Boutelle, C. O., Capt. Assistant C. S.
Brooke, J. M. Prof. Lexington, Va.
Campbell, J. B. Captain U. S. A.
Chase, Constantine, 1st Lieut. U.S.A.
Chase, Leslie, Esq. New York
Colwell, A. W., Esq., New York
Copeland, C. W., Esq. New York
Dobson, W. A., Esq. Bu. C. and R.
Falsen, C. M. Lieut. Norwegian N.
Faron, E., Esq. Orange, N. J.
Forster, E. J., M. D. Boston
Grice, F. E., Esq. Bu. C. and R.
Hillman, G., Esq. City Island, N. Y.
Hoffman, J. W., Esq. Philadelphia
Humphrey, E. W. C. Louisville
Hunt, W. P., Esq. Boston
Keckeler, A. T., M. D. Cincinnati
Le Baron, J. F. Asst. Eng. U. S. A.
Lyon, Henry, M. D. Boston
Maguire, E. Captain U. S. A.
Manton, J. P., Esq. Providence
Marx, J. L. Lieutenant R. N.
Mensing, A. Capt. Imp. G. Navy
Miller, H. W., Esq. Morristown, N. J.
Miller, P. P., Esq., Buffalo
Mullett, A. B., Esq. Washington
Myers, T. B., Esq. New York
Nordhoff, C., Esq. Alpine, N. J.
Oliver, W. L., Esq. San Francisco
Peck, R. H., Esq. New York
Powell, W. T., Esq. Bu. C. and R.
Reilly, H. J. 1st Lieut. U. S. A.
Reynolds, G. H., Esq. New York
Roepper, C. W., Esq. Alliance, O.
Ropes, J. C., Esq. Boston
Russell, A. H. 1st Lieut. U. S. A.
Sargent, C. S. Prof. Harvard Univ.
Scudder, E. M., Esq. New York
Simpson, J. M., Capt. Chilian Navy
Stratton, E. P., Esq. New York
Stueler, R., Esq. New York
Taber, H. S. Captain U. S. A.
Turtle, T. Captain U. S. A.
Tillman, S. E., Prof. West Point
Wellman, S. T., Esq. Cleveland
Wisser, J. P. 1st Lieut. U. S. A.
White, J. F., S. B. Torpedo Station
Willamov, G. Con.Gen. Russia, N.Y.
Wilson, A. E., Lieut. Chilian Navy
Woodall, W. E., Esq. Baltimore
Zalinski, E. L. 1st Lieut. U. S. A.

CORRESPONDING SOCIETIES.

United States.

American Academy of Arts and Sciences, Boston, Mass.
American Chemical Journal, Baltimore, Md.
American Geographical Society, New York City.
American Institute of Mining Engineers, New York City.
American Iron and Steel Association, Philadelphia, Pa.
American Metrological Society, Columbia School of Mines, New York City.
American Philosophical Society, Philadelphia, Pa.
American Society of Civil Engineers, New York City.
American Society of Mechanical Engineers, New York City.
Connecticut Academy of Arts and Sciences, New Haven, Conn.
Franklin Institute, Philadelphia, Pa.
Military Service Institution of the U. S., Governor's Island, N. Y.
Ohio Mechanics Institute, Cincinnati, O.
School of Mines Quarterly, New York City.

Foreign.

Association Parisienne des Propriétaires d'Appareils à Vapeur, Paris.
Giornale d'Artiglieria e Genio, Rome.
Hydrographisches Amt der Kaiserlichen Marine, Berlin.
Institute of Mining and Mechanical Engineers, Newcastle-upon-Tyne.
Institution of Civil Engineers, London.
Institution of Mechanical Engineers, London.
Mittheilungen a. d. Gebiete d. Seewesens, Pola.
Norsk Tidsskrift for Sovæsen, Horten, Norway.
Réunion des Officiers de Terre et de Mer, Paris.
Rivista Marittima, Rome.
Royal Artillery Institution, Woolwich.
Royal United Service Institution, London.
Société des Ingénieurs Civils, Paris.

NECROLOGY.

Hon. Gustavus V. Fox. Born at Saugus, Massachusetts, June 12, 1821. Appointed a Midshipman in the Navy, January 12, 1838. His first cruise was in the sloop-of-war Cyane. At the close of this cruise, after a short leave, and a year in the receiving ship at Boston, he was ordered, December 7, 1842, to the Saratoga. May 26, 1843, he was ordered to the Independence, from which he was detached September 28, 1843. From that date until May 28, 1844, he was attached to the Naval School at Philadelphia, and two days later he received his warrant as Passed Midshipman (No. 8), to rank as such from May 20, 1844. After two months on board the receiving ship at Boston, he was ordered, August 1, 1844, to the Preble, from which he was detached September 27, 1845, and granted three months' leave. April 16, 1846, he was ordered to duty in the Coast Survey, being appointed December 28 of the same year, Acting Master of the Washington. January 13, 1848, he was detached from the Coast Survey, and ordered to the Plymouth, as Acting Master, and later to the Dolphin. June 26, 1851, he was detached from the latter vessel, and granted three months' leave, at the close of which he was warranted a Master, from August 29, 1851. October 2, 1851, Fox was ordered to the receiving ship at Philadelphia, from which he was detached November 14, and granted six months' leave, with permission to be absent from the United States. His leave was subsequently renewed six months. During this period, he served in the steamer Baltic, of the Collins Line. He was commissioned a Lieutenant, December 31, 1852, to date from July 9, 1852, and on June 1, 1853, he was ordered to the Princeton. On August 12 of the same year he was detached and ordered to command the steamer Ohio, of the Chagres Line. March 28, 1854, he was transferred to the command of the steamer George Law, of the same line. On July 5, 1855, he was detached and granted furlough for one year; and on July 10, 1856, his resignation was accepted from the 30th instant. After his resignation, Mr. Fox became agent for the Bay State Woollen Mills, at Lawrence,

Massachusetts. At the outbreak of the Civil War, in February, 1861, Captain Fox was sent for by General Scott, for consultation in reference to throwing supplies into Fort Sumter; but the plan was not approved, and only adopted after the change in the Administration. Great delays were experienced in preparing the expedition, and it only left New York on April 8. The Powhatan, the most important vessel in the relief squadron, was withdrawn from the service at the last moment, and it was therefore impossible to carry out the original plan. The vessels arrived off Charleston on the 12th, and found that Fort Sumter was already attacked. The evacuation took place on the 14th, and Major Anderson and his command were taken on board the Baltic and carried to New York. Captain Fox was appointed Assistant Secretary of the Navy, May 9, 1861, and retained the position until November 26, 1866. The services which he rendered during the war are well known. As a professional man, and the highest official at the Department under the Secretary, his guiding influence was felt during the whole period. Of an ardent and impetuous temperament, and accustomed to meet and overcome obstacles, his force of character and resolution infused energy into the naval administration, while his professional skill kept it in the right path, and determined the course of naval operations. After the close of the war he was sent with the monitor Miantonomoh on a special mission to Russia, to offer to the Emperor the congratulations of the United States upon his escape from assassination. Upon the return of the mission, Captain Fox retired to private life. He died at New York, October 29, 1883, and was buried at Rock Creek Church, Washington, D. C.

Lieutenant Henry Loomis Green. Born, New York City, March 16, 1849. Appointed a Midshipman, July 31, 1866. Graduated from the Naval Academy, June 7, 1870. Ordered to the Plymouth, July 2, 1870; detached and placed on waiting orders, June 24, 1873. Commissioned an Ensign, July 13, 1871. Ordered to temporary duty on the Powhatan, November 16, 1873, and later to the Pinta. October 29, 1874, detached from Pinta. Commissioned a Master, May 23, 1874. January 2, 1875, ordered to special duty, Inter-Oceanic Survey. September 13, 1875, ordered to Gettysburg. June 14, 1876, detached and granted three months' leave. September 1, 1876, ordered to Hydrographic Office; detached March 28, 1877, and placed on waiting orders. April 25, 1877, ordered to Saratoga. February 25, 1880,

detached and placed on waiting orders. September 1, 1880, ordered to Naval Academy. Commissioned a Lieutenant, November 23, 1880. Summer of 1881 made cruise in practice ship Dale. Died, Annapolis, Md., July 7, 1883. Sea service, eight years, nine months; shore duty, six years, six months; total service, sixteen years, eleven months.

LIEUTENANT-COMMANDER CHARLES WILLIAM KENNEDY. Born, Canastota, New York, January 19, 1845. Appointed an Acting Midshipman from New York, September 25, 1861. Graduated from the Naval Academy, November 22, 1864. February 1, 1865, ordered to report to Rear-Admiral Paulding, for duty at New York. March 30, 1865, detached and ordered to the Susquehanna, South Atlantic Squadron, then transferred to the Nipsic. November 1, 1866, commissioned an Ensign. December 1, 1866, commissioned a Master. October 11, 1867, detached from the Nipsic and placed on waiting orders. January 15, 1868, ordered to the Kearsarge, South Pacific Squadron. March 12, 1868, commissioned a Lieutenant. April 9, 1869, commissioned a Lieutenant-Commander, from March 26, 1869. Transferred to the Saranac. January 18, 1871, detached from the Saranac and placed on waiting orders. April 28, 1871, ordered to duty in the Coast Survey. March 30, 1874, detached from the Coast Survey steamer Hassler and placed on waiting orders. August 14, 1874, Naval Academy. Practice ship Constellation, summer of 1877. September 15, 1878, detached from the Naval Academy and placed on waiting orders. September 18, 1878, ordered to the Quinnebaug. Transferred to Wyoming. May 26, 1881, detached and placed on waiting orders. June 17, 1881, Naval Academy. June 30, 1882, detached and ordered as Assistant to Lighthouse Inspector, 11th District. Died, Las Vegas, New Mexico, November 30, 1883. Sea service, eleven years, ten months; shore duty, nine years, two months; total service, twenty-two years, two months.

PASSED ASSISTANT PAYMASTER CALLENDER IRVINE LEWIS. Born, Pennsylvania, August 16, 1853. Appointed an Assistant Paymaster, June 23, 1877. July 7, 1877, ordered to the Bureau of Provisions and Clothing. September 4, 1877, detached and ordered to the Guard. November 29, 1878, detached from the Guard and ordered to settle accounts. May 13, 1879, ordered to Naval Station, New London, Connecticut. September 30, 1879, detached and or-

dered to the Saratoga. September 30, 1881, detached and ordered to settle accounts. Commissioned a Passed Assistant Paymaster, August 31, 1881. February 3, 1882, ordered to Naval Station, New London, Connecticut. Detached October 1, 1882, and ordered to settle accounts and await orders. Died, Frankfort, Kentucky, August 8, 1883. Sea service, three years, two months; shore duty, one year, five months; total service, six years, two months.

Rear-Admiral Edward Middleton. Born, South Carolina, December 10, 1810. Appointed a Midshipman, July 1, 1828. Frigate Java, Mediterranean Squadron, October, 1828, to May, 1831. Sloop-of-war Vandalia, West India Squadron, 1831–3. Receiving ship Brooklyn, 1833–4. Promoted to Past-Midshipman, June 14, 1834. Frigate Constitution, Mediterranean Squadron, 1835–8. Sloop-of-war Marion, Brazil Squadron, 1839–1842. Commissioned a Lieutenant, February 25, 1841. Store-ship Lexington, 1843–4. Sloop-of-war Plymouth, Mediterranean Squadron, 1844–5. Frigate Cumberland, Home Squadron, 1846. Steamer Princeton, 1847–9. Store-ship Erie, 1849. Navy Yard, Philadelphia, 1849–51. Razee-frigate Independence, Mediterranean Squadron, 1852. Receiving-ship, New York, 1853. Executive Officer of the sloop-of-war Decatur, Pacific Squadron, 1854–6. Operating against a combination of the hostile Indians of the various tribes of Washington and Oregon Territories during the winter of 1854–5. Present at attack upon Seattle, Washington Territory, January 26, 1856. Commissioned a Commander, January 26, 1856. Commanding sloop-of-war Decatur, 1856–7. Commanding sloop-of-war St. Mary's and steamer Saranac, at different times, Pacific Squadron, 1861–5. Commissioned a Captain, April 24, 1863. Special duty, New York, 1866. Navy Yard, Mare Island, California, 1867–8. Commanding steamer Pensacola, Pacific Squadron, 1868–9. Commissioned a Commodore, November 26, 1868. Commanding steamer Lackawanna, Pacific Squadron, 1869. Commandant, Navy Yard, Pensacola, Florida, 1870. Placed on retired list December 11, 1872, with the rank of Commodore. Promoted to Rear-Admiral on retired list, August 15, 1876. Died, Washington, D. C., April 27, 1883. Sea-service, twenty-two years; shore duty, eight years, seven months; total service, fifty-four years, ten months.

Naval Cadet Peter Miller. Born, Stockholm, Sweden, February 5, 1860. Appointed a Cadet Engineer, October 1, 1878. Graduated from the Naval Academy, June 8, 1882. Ordered to the

Tennessee, July 26, 1882. Died on board the Tennessee, April 3, 1883, at Key West, Florida, having been severely scalded the day previous by the bursting of a steam-pipe while on duty in the fire-room. Sea service, one year, four months; shore duty, three years, one month; total service, four years, six months.

Captain Norval Lane Nokes, U. S. M. C. Born, District of Columbia, April 3, 1841. Commissioned a 2d Lieutenant, November 25, 1861. Marine Barracks, Brooklyn, 1862. Sloop-of-war Vincennes, West Gulf Blockading Squadron, 1863. Commissioned a 1st Lieutenant, June 30, 1863. Steamer Pensacola, West Gulf Blockading Squadron, 1863-4. Marine Barracks, Washington, 1865-6. Ossipee, North Pacific Squadron, 1866-8. Headquarters, Washington, 1869-70. Navy Yard, Norfolk, 1871-2. Commissioned a Captain, 1872. Fleet Marine Officer, North Atlantic Station, 1872-75. Marine Barracks, Washington, 1875-8. Marine Barracks, Mare Island, 1879-80. Ordered to Flagship Hartford, as Fleet Marine Officer, Pacific Station, June, 1882. Died, Corinto, Nicaragua, October 7, 1883. Sea service, seven years, two months; shore duty, thirteen years, nine months; total service, twenty years, eleven months.

Lieutenant Bontelle Noyes. Born, Maine, January 10, 1848. Appointed a Midshipman, September 26, 1864, and graduated from the Naval Academy, June 2, 1868. September 3, 1868, ordered to the Guerriere. July 31, 1869, was detached from Guerriere and ordered home. August 16, 1869, commissioned an Ensign from April 19, 1869. September 10, 1869, granted permission to proceed to Europe to join the European Squadron, and was assigned to duty on board the Plymouth. Later he was transferred to the Juniata. July 12, 1870, commissioned a Master. July 1, 1872, detached from the Juniata, and ordered to report on September 1, at Newport, R. I., for Torpedo Instruction. February 14, 1873, commissioned a Lieutenant. June 30, 1873, detached from the Torpedo Station and placed on waiting orders. August 15, 1873, was ordered to the Flagship Pensacola, on the Pacific Station. Served on the Richmond, same station. October 20, 1876, was detached from the Richmond and placed on sick leave. From November 9, 1877 to February 15, 1881, served on board the training ship Minnesota. August 1, 1881, was ordered to take passage in the Powhatan, on the 15th inst., for Aspinwall to join the Richmond, and reported on that vessel September 30 following. He was killed on board the Richmond, at

Yokohama, Japan, on August 29, 1883, by the falling of the foretop-gallantmast while exercising with spars. Sea service, eleven years, eight months; shore duty, four years, seven months; total service, eighteen years, six months.

Rear-Admiral Benjamin Franklin Sands. Born, Maryland, February 11, 1812. Appointed a Midshipman, April 1, 1828. May 31, 1828, ordered to the Naval School at New York. October 15, detached and ordered to the Vandalia. December 31, 1831, detached and granted leave. August 8, 1832, ordered to the St. Louis. July 31, 1833, detached and granted leave. October 12, 1833, ordered to the Naval School at Norfolk, Va. June 14, 1834, promoted to Passed Midshipman. March 18, 1835, ordered to duty in the Coast Survey. March 16, 1840, promoted to Lieutenant. August 9, 1842, detached from Coast Survey duty and ordered to the Columbus. May 29, 1844, detached and granted leave of absence. June 26, 1844, ordered to the Depot of Charts. December 28, 1846, detached and ordered to the brig Washington. September 1, 1847, detached and granted leave. December 2, 1847, ordered to the brig Porpoise. April 4, 1850, detached from the command of the Porpoise and granted leave. May 14, 1850, ordered to command the brig Washington. September 26, 1850, detached from command of the Washington, and ordered to remain on duty in the Coast Survey. September 14, 1855, promoted to Commander. September 28, 1858, detached from duty in the Coast Survey and ordered to the Bureau of Construction. December 12, 1860, detached and placed on waiting orders. May 23, 1861, ordered to Coast Survey duty. July 16, 1862, promoted to Captain. October 11, 1862, detached from duty in the Coast Survey. November 18, 1862, ordered to command the Dakota. June 22d, 1863, ordered to the temporary command of the Roanoke. October 31, 1863, detached and ordered to command the Fort Jackson. July 31, 1865, detached and ordered to the Navy Yard, Boston, Massachusetts. July 25, 1866, promoted to Commodore. December 15, 1866, detached and placed on waiting orders. May 8, 1867, ordered as Superintendent Naval Observatory. April 27, 1871, promoted to Rear-Admiral. February 11, 1874, placed on retired list. February 23, 1874, detached from Naval Observatory. Died, Washington, D. C., June 30, 1883. Sea service, twenty years, three months; shore duty, twenty-two years, two months; total service, fifty-five years, three months.

CONSTITUTION:

Title.

Article I. The organization shall be known as the United States Naval Institute.

Object.

Art. II. Its object shall be the advancement of professional and scientific knowledge in the Navy.

Organization and Officers.

Art. III, Sec. 1. The officers and permanent committees of the Society shall include:

A President.
A Vice-President.
A Secretary.
A Corresponding Secretary. } Executive Committee.
A Treasurer.
A Committee on Publication.
Vice-Presidents and Corresponding Secretaries of Branches.

Sec. 2. Special Committees may at any time be appointed, by a majority vote of the Society, to consider questions not properly under the cognizance of the Standing Committees.

Membership.

Art. IV, Sec. 1. The Institute shall consist of members, life members, honorary members, and associates.

Sec. 2. All officers of the Navy, Marine Corps, and all civil officers attached to the Naval service shall be entitled to become members, without ballot, on payment of dues to the Treasurer, or to the Corresponding Secretary on the station. Other persons may become members, on election by ballot, under the rules governing the election of honorary and associate members (see Art. IV, Sec. 6), and

on payment of dues; provided that the number of members not officially connected with the Navy shall not at any time exceed (50) fifty.

SEC. 3. All those who are entitled to become members, may become life members, on payment of thirty dollars. As a reward for extraordinary services to the Institute, or as a mark of honor, the Institute may create life members without payment of dues. Nominations for life members must be made by the Executive Committee, and a majority vote of members shall be required to elect the candidate. The Prize Essayist of each year shall be a life member without payment of dues.

SEC. 4. Honorary members shall be selected from distinguished Naval and Military officers, and from eminent men of learning in civil life; provided that the number of such members shall in no case exceed thirty. The Secretary of the Navy shall be, *ex officio*, an honorary member.

SEC. 5. Associates shall be chosen from persons connected with the Naval and Military professions, and from persons in civil life who may be interested in the objects that it is the design of the Institute to advance.

SEC. 6. Honorary members and associates shall be elected as follows: Nominations shall be made in writing to the Executive Committee, and such nominations, with the name of the member making them, shall be entered on the minutes of the Committee. At the succeeding meeting of the Institute the Committee shall report. If their report be favorable, a majority of the members present shall decide the election; but if unfavorable, a two-thirds vote shall be required to elect the candidate. Two members of the Executive Committee shall constitute a quorum for carrying out the requirements of this section.

SEC. 7. The annual dues for members and associate members shall be three dollars, payable upon joining the Institute, and upon the first day of each succeeding January.

SEC. 8. Membership shall be forfeited in cases when the recommendation of the Executive Committee, supported by a two-thirds vote of the Society, shall so determine, and members two years in arrears shall be dropped. Those who have been dropped from the list of members for being two years in arrears can only regain their membership by paying up their arrears.

Nominations and Elections.

Art. V, Sec. 1. There shall be a meeting of the Society on the second Thursday in January of each year, at which all officers shall be chosen, except as provided in Art. VIII, Secs. 6 and 7.

Sec. 2. Members not in attendance may vote by proxy at such elections as well as upon questions relating to the Constitution and By-Laws, but vote by proxy will only be allowed in the two cases herein specified. Life members have full rights with members to vote on any question. Honorary members and associates will not be allowed to vote on any question.

Sec. 3. A majority of votes recorded shall determine choice.

Sec. 4. Members elected to the position of officers of the Society will assume their duties as soon as notified.

Sec. 5. Vacancies may be temporarily filled by the Executive Committee, but regular nominations and elections shall follow as soon as practicable.

Sec. 6. All voting for officers shall be by ballot, in session of the Society.

Duties of Officers.

Art. VI, Sec. 1. The President, or, in his absence, the Vice-President, or, in the absence of both, a member of the Executive Committee, will preside in executive session.

Sec. 2. The transaction of all financial, executive or administrative business, in which latter shall be included censorship of papers offered for presentation to the Society, shall be in the hands of the Executive Committee. The Committee will determine for itself its routine of business and form of record.

Sec. 3. The Secretary shall keep a register of the members, a copy of the Constitution and By-Laws in which he shall note all changes, a journal of the proceedings of the Society, a separate record of the proceedings of the Executive Committee, and a file-book in which the reports of committees shall be entered. These books shall be at all times in readiness for inspection. Papers offered by members unable to be present, if accepted by the Executive Committee, shall be read by the Secretary. He shall give due notice of all meetings of the Society, and shall have control of the stenographer and copyists employed to prepare records of the proceedings.

Sec. 4. The Corresponding Secretary shall attend to all correspondence and keep a record thereof.

SEC. 5. The Treasurer, under the direction of the Executive Committee, shall be the disbursing officer. He shall keep a receipt and expenditure book, and an account current with each member. He will submit his books for examination whenever asked for.

SEC. 6. The Committee on Publication shall have charge of the printing and publication of all papers and proceedings of the Society.

MEETINGS.

ART. VII, SEC. 1. There shall be a meeting of the Society on the second Thursday of each month for the discussion of professsional and scientific subjects.

SEC. 2. Special meetings may be called by the Secretary at the request of one or more of the general officers, or of standing or special committees.

SEC. 3. A stenographer shall be employed to keep the record of all proceedings of regular meetings.

SEC. 4. Annually, or as much oftener as the Executive Committee may decide, a record of papers read before the Society and the discussions growing out of them shall be published in pamphlet form. Papers on intricate technical subjects may be published as a part of the proceedings of the Society without being publicly read, if, in the opinion of the Executive Committee, the subject to which they relate be not of a character to be appreciated on merely casual investigation.

BRANCHES.

ART. VIII, SEC. 1. The Executive Committee is empowered to appoint temporary Corresponding Secretaries for all Naval Stations, both ashore and afloat, where there is no organized Branch ; also for Branches where a vacancy exists owing to the resignation of the Corresponding Secretary before a meeting can be called to elect a successor.

SEC. 2. The officers shall be a Vice-President, Corresponding Secretary, and an Executive Committee, composed of the Vice-President and Secretary, *ex officio*, and one other member.

SEC. 3. The Vice-President of the Branch shall perform the same duty for the Branch as prescribed for the President of the Institute.

SEC. 4. The Corresponding Secretary of a Branch shall keep a register of the members, honorary members and associate members

of the Institute residing within the limits of the station, a copy of the Constitution and By-Laws in which he shall note all changes, and a journal of the proceedings of the Branch. He shall give due notice of all meetings of the Branch, and shall have control of the stenographer and copyist employed to prepare the records of the proceedings. He shall forward to the Corresponding Secretary of the Institute all papers read before his Branch, and shall keep him informed of all new members and their addresses, and of all business, not financial, relating to the Institute. He shall have charge of the library, and of all books and papers, and shall receive and distribute publications. He shall keep a receipt and expenditure book, shall collect dues from all the members on his station, and give receipts therefor. He shall be authorized to expend the funds in his possession for stationery, postage and printing, and for such other expenses as the Executive Committee of his Branch may authorize. He shall, at the end of every month, render to the Treasurer a detailed statement of moneys received, with the names of members from whom received, and shall, at the end of every month, forward to the Treasurer all funds remaining in his hands and vouchers for money expended, retaining sufficient money to defray the current expenses of the Branch.

SEC. 5. Those members of the Institute residing within the limits of a station where a Branch is established shall be enrolled on the books of the Corresponding Secretary of that Branch during the time of their residence on the station; they will pay him their dues, keep him informed of their addresses, and receive from him their copies of the publications.

SEC. 6. Monthly meetings of each Branch shall be held, upon such dates as the Branch shall decide, and other meetings at the call of its Executive Committee. It shall be the duty of the Executive Committee of the Branch to call an annual meeting for the election of officers of the Institute, at a sufficient time prior to the regular meeting of the Institute at Annapolis for the election of officers to enable the Corresponding Secretary to forward the votes to the Corresponding Secretary of the Institute. Votes not received at the regular annual meeting of the Institute shall be invalid.

SEC. 7. The officers of a Branch shall be elected for one year, at the first annual meeting of the Branch. All voting for officers shall be by ballot, in executive session. In the event of the appointment of a temporary Corresponding Secretary and his acceptance of the

appointment, it shall be his duty to call a meeting of all members within the limits of his station at least one month after his appointment, to organize the Branch, by the election of officers, who shall hold office until the regular annual election.

SEC. 8. All papers offered must be submitted for examination to the Executive Committee of the Branch, and if by them accepted they may be read before the Branch and published in the Proceedings. But the Executive Committee of the Institute has a final censorship of all papers before they are published. Papers should be read by authors, or, in their absence, by the Corresponding Secretary, unless the author designates a particular person whom he wishes to read the paper.

PAPERS AND PROCEEDINGS.

ART. IX, SEC. 1. The papers and proceedings of the Institute shall constitute assets, and be so borne on the books of the Treasurer and accounted for.

SEC. 2. One copy of the Proceedings, when published, shall be furnished to each member, life member, honorary member, and associate member, the Library of the Naval Academy, Corresponding Societies, Congressional Library, Boston Public Library, Library of Harvard University, and Naval Library at Mare Island.

SEC. 3. Back numbers of Proceedings shall be furnished to members at a charge which shall be fixed by the Executive Committee. The Proceedings may be furnished to non-members at a cost ten per cent. higher than that at which they are furnished to members.

SEC. 4. No copies shall be furnished to members who are one year in arrear.

AMENDMENTS.

ART. X. No addition nor amendment to the Constitution and By-Laws shall be made without the assent of two-thirds of the members voting. Notice of proposed changes or additions shall be given by the Secretary, at least one month before action is taken upon them.

BY-LAWS.

ARTICLE I. The rules of the United States House of Representatives shall, in so far as applicable, govern the parliamentary proceedings of the Society.

ART. II. 1. At both regular and stated meetings the routine of business shall be as follows:

2. At executive meetings, the President, or in his absence the Vice-President, or, in the absence of both, a member of the Executive Committee, will call the meeting to order, and occupy the chair during the session; in the absence of these, the Society will appoint a Chairman.

3. At meetings for the presentation of papers and discussions, the Society will be called to order as above provided, and a Chairman will be appointed by the presiding officer, reference being had to the subject about to be discussed, and an expert in the specialty to which it relates selected.

4. At regular meetings, after the presentation of the paper of the evening, or on the termination of the arguments made by members appointed to, or voluntarily appearing to enter into formal discussion, the Chairman will make such review of the paper as he may deem proper. Informal discussion will then be in order, each speaker being allowed not exceeding ten minutes in the aggregate, unless by special agreement of the Society. The author of the paper will, in conclusion, be allowed such time in making a résumé of the discussion as he may deem necessary. The discussion ended, the Chairman will close the proceedings with such remarks as he may be pleased to offer.

5. At the close of the concluding remarks of the Chairman, the Society will go into executive session, as hereinbefore provided, for the transaction of business, as follows:

1. Stated business, if there shall be any to be considered.
2. Unfinished business taken up.
3. Reports of Officers or Committees.
4. Applications for membership reported.
5. Correspondence read.
6. Miscellaneous business transacted.
7. New business introduced.
8. Adjournment.

NAVAL INSTITUTE PRIZE ESSAYS, 1879–1884.

1879.

Subject:—"NAVAL EDUCATION.—I. OFFICERS. II. MEN."

Judges of Award:—CHARLES W. ELIOT, President of Harvard University; DANIEL AMMEN, Rear-Admiral, U. S. N.; WM. H. SHOCK, Engineer-in-chief, U. S. N.

Winner of the Prize:—Lieutenant-Commander ALLAN D. BROWN, U. S. N. *Motto of Essay:*—"Qui non proficit."

First Honorable Mention:—Lieutenant-Commander CASPAR F. GOODRICH, U. S. N. *Motto of Essay:*—"Esse quam videri."

Second Honorable Mention:—Commander ALFRED T. MAHAN, U. S. N. *Motto of Essay:*—"Essayons."

Number of Essays presented for competition, ten.

1880.

Subject:—"THE NAVAL POLICY OF THE UNITED STATES."

Judges of Award:—Hon. WM. M. EVARTS, Secretary of State; Hon. R. W. THOMPSON, Secretary of the Navy; Hon. J. R. MCPHERSON, U. S. Senator.

Winner of the Prize:—Lieutenant CHARLES BELKNAP, U. S. N. *Motto of Essay:*—"Sat cito, si sat bene."

Number of Essays presented for competition, eight.

1881.

Subject:—"THE TYPE OF (I) ARMORED VESSEL, (II) CRUISER, BEST SUITED TO THE PRESENT NEEDS OF THE UNITED STATES."

Judges of Award:—Commodore W. N. JEFFERS, U. S. N.; Chief Engineer J. W. KING, U. S. N.; Chief Constructor JOHN LENTHALL, U. S. N.

Winner of the Prize by decision of two of the Judges:—Lieutenant EDWARD W. VERY, U. S. N. *Motto of Essay:*—"Aut Cæsar, aut nullus."

Recommended for the Prize by one of the Judges:—Lieutenant SEATON SCHROEDER, U. S. N. *Motto of Essay:*—"In via virtute via nulla."

Number of Essays presented for competition, four.

1882.

Subject:—"OUR MERCHANT MARINE; THE CAUSES OF ITS DECLINE AND THE MEANS TO BE TAKEN FOR ITS REVIVAL."

Judges of Award:—Hon. HAMILTON FISH, Ex-Secretary of State; JOHN D. JONES, President Atlantic Mutual Insurance Company, New York; A. A. LOWE, Ex-President New York Chamber of Commerce.

Winner of the Prize:—Lieutenant JAMES D. J. KELLEY, U. S. N. *Motto of Essay:*—"Nil clarius aquis."

First Honorable Mention:—Master CARLOS G. CALKINS, U. S. N. *Motto of Essay:*—"Mais il faut cultiver notre jardin."

Second Honorable Mention:—Lieutenant-Commander F. E. CHADWICK, U. S. N. *Motto of Essay:*—"Spero meliora."

Third Honorable Mention:—Lieutenant RICHARD WAINWRIGHT, U. S. N. *Motto of Essay:*—"Causa latet: vis est notissima."

Essay printed by request of John D. Jones, Esq. Ensign W. G. DAVID, U. S. N. *Motto of Essay:*—"Tempori parendum."

Number of Essays presented for competition, eleven.

1883.

Subject:—"HOW MAY THE SPHERE OF USEFULNESS OF NAVAL OFFICERS BE EXTENDED IN TIME OF PEACE WITH ADVANTAGE TO THE COUNTRY AND THE NAVAL SERVICE?"

Judges of Award:—Hon. ALEXANDER H. RICE; Judge JOSIAH G. ABBOTT; Rear-Admiral GEORGE H. PREBLE, U. S. N.

Winner of the Prize:—Lieutenant CARLOS G. CALKINS, U. S. N. *Motto of Essay:*—"Pour encourager les autres."

First Honorable Mention:—Commander N. H. FARQUHAR, U. S. N. *Motto of Essay:*—"Semper paratus."

Second Honorable Mention:—Captain A. P. COOKE, U. S. N. *Motto of Essay:*—"Cuilibet in arte suâ credendum est."

Number of Essays presented for competition, four.

1884.

Subject:—"THE BEST METHOD FOR THE RECONSTRUCTION AND INCREASE OF THE NAVY."

Judges of Award:—Rear-Admiral C. R. P. RODGERS, U. S. N.; D. C. GILMAN, LL. D., President of the Johns Hopkins University; Hon. J. R. HAWLEY, U. S. Senator.

Number of Essays presented for competition, two.

PROCEEDINGS

OF THE

UNITED STATES NAVAL INSTITUTE,

ANNAPOLIS, MD.

Organized October 9th, 1873, at the U. S. Naval Academy.

Issued Quarterly. Annual Subscription, $3.50. Single Copy, $1.00.
Annual Dues for Members and Associate Members, $3. Life Membership Fee, $30.

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VOLUME V, No. 5—(Continued.)

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VOLUME VI, No. 2. WHOLE No. 12. 1880.

VOLUME VI, No. 3. WHOLE No. 13. 1880.

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VOLUME VII, No. 1. Whole No. 15. 1881.

VOLUME VII, No. 2. Whole No. 16. 1881.

VOLUME VII, No. 3. Whole No. 17. 1881.

VOLUME VII, No. 4. Whole No. 18. 1881.

VOLUME VIII, No. 1. Whole No. 19. 1882.

VOLUME VIII, No. 1—(Continued.)

VOLUME VIII, No. 2. WHOLE No. 20. 1882.

VOLUME VIII, No. 2—(Continued.)

VOLUME VIII, No. 3. WHOLE No. 21. 1882.

VOLUME VIII, No. 4. WHOLE No. 22. 1882.

VOLUME VIII, No. 4—(Continued.)

VOLUME IX, No. 1. Whole No. 23. 1883.

VOLUME IX, No. 2. Whole No. 24. 1883.

VOLUME IX, No. 2—(Continued.)

ANNUAL REPORT OF THE SECRETARY.

Mr. President, and Members of the Naval Institute:

I have the honor to submit the following report concerning the affairs of the Naval Institute for the year 1883.

	Jan. 1883.	Jan. 1884.	Increase.
Members	547	583	36
Life members	15	36	21
Honorary members	9	9	...
Associate members	20	58	38
Corresponding Societies, Home	12	14	2
Corresponding Societies, Foreign.	10	13	3
Periodicals, Home	7	10	3
Periodicals, Foreign	8	8	...
Libraries	8	8	...
Subscribers	11	16	5
Navy Department	25	25	...
Bureau of Navigation	50	50	...
War Department	...	100	100
Total issue	722	930	208

	Members.	Life Members.	Hon. Members.	Asso. Members.
Joined	100	18	1	41
Reinstated	5	...	...	...
Resigned	54	...	...	1
Died	8	...	1	...
Dropped	6	...	...	...
Transferred to Life Member	1	...	...	2
Transferred from Member	...	1	...	...
Transferred from Associate Member.	...	2	...	...
Increase	36	21	...	38

Sales of the Proceedings during the year 1883:

Complete sets, bound in volumes, 17	380	copies.
Single copies	2680	"
Total	3060	"
Reprints from the Proceedings sold	1309	

Orders for the greater part of the above mentioned sales were received through Lieutenant John H. Moore, U. S. N., Corresponding Secretary, Washington Branch.

In order to replenish the stock of those numbers of the Proceedings, the edition of which was exhausted or nearly so, it has been found necessary to obtain 134 copies of the Proceedings by purchase from members and book-dealers.

Proceeedings on hand April 13th, 1882	1403	copies.
" " " March 14th, 1883	2689	"
" " " January 1st, 1884	4935	"

Since January 1, 1883, six numbers of the Proceedings have been issued, viz:

Vol. VIII. No. 4, Whole No. 22	1400	copies ordered.
Vol. IX. No. 1, Whole No. 23.	1100	"
Vol. IX. No. 2, Whole No. 24	1100	"
Vol. IX. No. 3, Whole No. 25	3000	"
Vol. IX. No. 4, Whole No. 26	3000	"
Vol. IX. No. 5, Whole No. 27	1300	"
	10900	

In addition to the above, a second edition of Vol. II. (Whole No. 2), 300 copies, was received from the printer in February last.

A second edition of Vol. VI. No. 1, Whole No. 11, is now being printed, and it is expected that the edition, 250 copies, will be ready for delivery next month. The material for Nos. 28 and 29 is now in the hands of the printer. The former number will be issued about February 1st next, and the latter number a month later.

Electrotype plates of the Chicago, Boston, Dolphin, from No. 26, were sold to the following papers, viz. Chicago *News*, San Francisco *Chronicle*, New York *Herald*, Boston *Herald*, Philadelphia *Record*,

Washington *National Republican*, *Army and Navy Journal*; *Army and Navy Register*. Electrotypes of all the plates from No. 26 have recently been sold to the Navy Department.

Complete sets of the Proceedings have been exchanged with the American Chemical Journal, Baltimore, Md., also with the Institution of Civil Engineers, London, England.

The following Corresponding Societies have been added to our list of exchanges, during the past year, viz.

UNITED STATES.

American Chemical Journal, Baltimore, Md.
American Iron and Steel Association, Philadelphia, Pa.
Connecticut Society of Arts and Sciences, New Haven, Conn.

FOREIGN.

Institution of Civil Engineers, London, England.
Norsk Tidsskrift for Sovæsen, Horten, Norway.

I regret to state that but two essays have been received in competition for the Prize of 1884. The following gentlemen were invited to serve as the Judges of Award, and have kindly accepted the task imposed upon them, viz. Rear-Admiral C. R. P. Rodgers, U. S. N.; Hon. Joseph R. Hawley, U. S. Senator from Connecticut; D. C. Gilman, LL. D., President Johns Hopkins University, Baltimore, Md.

Very respectfully,

CHARLES M. THOMAS,
Secretary.

ANNAPOLIS, MD., *January* 10, 1884.

ANNUAL REPORT OF THE TREASURER.

U. S. NAVAL ACADEMY,
ANNAPOLIS, MD., *January* 11*th*, 1884.

TO THE PRESIDENT, OFFICERS AND MEMBERS
OF THE UNITED STATES NAVAL INSTITUTE:

Gentlemen:—The Treasurer's statement for the year 1883 is as follows:

RECEIPTS.

From balance on hand January 1, 1883, as per last statement,	$ 317 83
From dues,	2060 34
From sales of Proceedings and Reprints,	3253 00
From subscriptions,	396 95
From binding,	240 89
From sales of electrotypes,	130 00
From fees of twenty new life members,	600 00
From interest on $800 in 4 per cent. U. S. Bonds,	32 00
Total,	$7031 01

EXPENDITURES.

For postage, freight, expressage, telegraphing, and other expenses at headquarters,	$ 285 97	
For stationery, blanks and blank books for use at headquarters,	104 88	
For expenses of Branches,	62 93	
For printing Proceedings and Reprints,	3768 05	
For engraving and lithographing for same,	922 30	
For purchase of back numbers of Proceedings,	72 25	
For purchase of $1000 D. C. 3.65 Bond @ 1.11½,	1115 00	
For prize essay 1883,	150 00	
For advertising,	36 10	
For copyright fee for six numbers Proceedings,	6 00	
Total,		$6523 48
Balance on hand January 1, 1884,		$ 507 53

The above statement is sufficiently expressive of the present financial stability and the growing prosperity of the Institute, but I have to add that every obligation for the year 1883 has been paid, and that there is still due the Institute, and sure to be paid, $88.91 for publications furnished during the last months of the past year.

There is also due from members in arrears, $3 for 1881, $21 for 1882, and $201.50 for 1883. My experience as Treasurer begets the belief that at least nine-tenths of these dues will be paid.

The market value of the $1800 in United States and District of Columbia bonds owned by the Institute is now $2128, which is an advance of $63.48 beyond their original cost.

There are on hand 4935 of the back numbers of the Proceedings of the Institute. It is impossible to state their exact or even approximate value. They have all been paid for, so that whatever may hereafter be received from their sale will be a clear gain to the Institute. From the large sales of the past year it is safe to say that their future sales will constitute an ample reserve fund to protect and guarantee the interests of the yearly members, and the Institute's continued success will increase their money value from year to year.

At the beginning of this year, for reasons other than any abatement of my interest in the work and purposes of the Institute, I was compelled to resign the position of Treasurer, which I have held since October 24, 1881, and my successor, Lieutenant J. B. Briggs, has been elected. Whatever prosperity has come to the Institute during the period of my treasurership has been chiefly due to the wise management and steadfast and painstaking energy and industry of the Secretary, Lieutenant-Commander C. M. Thomas, and to the conquering force and fertile zeal of the Corresponding Secretary of the Washington Branch, Lieutenant John H. Moore (who during the past year has collected on behalf of the Institute $4374.85), and the thoughtful research and literary skill of its contributors. My part has been the modest one of recording the financial results of their labors; but, humble as my work has been, I shall always look back to it with pride, for I believe in the beneficent influences of the Institute—in its results, its purposes and its future success; and it is mainly to repeat this creed that I have intruded herein any mention of myself.

ROBERT W. ALLEN,

Paymaster U. S. N., and Treasurer U. S. Naval Institute.

Vol. X., No. 1. 1884. Whole No. 28.

PROCEEDINGS

OF THE

UNITED STATES

NAVAL INSTITUTE.

VOLUME X.

RESEARCHES ON THE EFFECTS OF POWDER.

(1874-1878.)

By M. E SARRAU, Ingénieur des Poudres et Salpêtres.

Translated by Lieutenants J. F. Meigs and R. R. Ingersoll, U. S. N.

PUBLISHED QUARTERLY BY THE INSTITUTE,

ANNAPOLIS, MD.

PRESS OF ISAAC FRIEDENWALD,
BALTIMORE, MD.

THE PROCEEDINGS

OF THE

UNITED STATES NAVAL INSTITUTE.

Vol. X. No. 1. 1884. Whole No. 28.

NAVAL INSTITUTE, ANNAPOLIS, MD.

JANUARY, 1884.

RESEARCHES ON THE EFFECTS OF POWDER.

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PART I.

THEORETICAL RESEARCHES ON THE EFFECTS OF GUNPOWDER AND OTHER EXPLOSIVES.

CHAPTER I.

PROPERTIES OF GASES.

1. *Mariotte's and Gay-Lussac's Laws.*—Gases and superheated vapors tend towards a limiting state, called that of a perfect gas, which is characterized by the two following laws:

1. *Mariotte's Law.*—The pressures of the same mass of gas are inversely proportional to the volumes.

2. *Gay-Lussac's Law.*—All gases have the same coefficient of dilatation under constant pressure, and this coefficient is independent of the pressure.

These two laws are expressed by the equation,

$$pv = K(1 + \alpha t); \quad (1)$$

where v is the volume of unit of weight of the gas, p the pressure, t the temperature, α the coefficient of dilatation under constant pressure, and K a constant depending upon the nature of the gas.

2. *Absolute Temperature.*—The coefficient of dilatation α, which is the same for all perfect gases according to Gay-Lussac's law, is $\frac{1}{273}$, nearly, according to the experiments of Regnault. Consequently, equation (1) becomes,

$$pv = \frac{K}{273}(273 + t). \tag{2}$$

The factor $(273 + t)$ is called the absolute temperature in the dynamic theory of heat. It is the centigrade temperature counted from a zero placed 273 degrees below the ordinary zero.

3. *Specific Volume.*—If we call p_0 the normal atmospheric pressure, and put $K = p_0 v_0$, equation (2) may be written,

$$pv = \frac{p_0 v_0}{273}(273 + t), \tag{3}$$

and, in this form, we see that v_0 is the value of v which corresponds to the values $t = 0$ and $p = p_0$ of the temperature and pressure.

This constant, which is called the specific volume, represents then the volume of unit of weight of the gas at zero temperature, and under the normal pressure; if the gas under consideration can reach these conditions of pressure and temperature without change of state and without ceasing to satisfy Mariotte's and Gay-Lussac's laws, its numerical value is the reciprocal of the specific weight, or weight of the unit of volume at zero and under the pressure p_0.

The specific volume ceases evidently to have this signification for gases and vapors which are in the state of a perfect gas only at temperatures above zero. Its definition results from equation (3), which the gas under consideration must satisfy in the limiting state; its numerical value may be derived from that equation by determining by experiment, in the physical conditions where the equation is applicable, a system of values corresponding to p, v, and t.

The determination of specific volumes, or, what is the same thing, the densities of gases and vapors, is of great importance in chemistry; and they have been the object of the research of many eminent scientists. We shall return, at the end of this chapter, to the physical laws which have been established, dwelling particularly upon those which are useful in the approximate calculation of the force of explosive substances.

4. *Specific Heat.*—The specific heat of a substance is the quantity of heat necessary to raise unit of weight of the substance one degree centigrade. The quantity may be measured in two ways: the body which is being heated may be allowed to expand freely under a deter-

mined pressure, or the volume of the body may be maintained constant; in the first case the specific heat is of constant pressure, and in the second of constant volume.

Calorimetric experiments have established the following law, which, like those of Mariotte and Gay-Lussac, appears to characterize the state of the perfect gas:

The specific heats under constant pressure and constant volume are independent of the pressure and volume.

This law has been experimentally verified by Regnault by the direct determination of specific heats under constant pressure.

As to the specific heats for constant volume, their direct measurement being almost impossible, this verification cannot be made. The law appears, however, sufficiently confirmed by the indirect measurement which has been made, of the relation between the specific heats throughout a considerable range of temperature and pressure, by many investigators.

5. *Conversion of Heat into Work by the Expansion of Gas.*—The above laws being established, we may deduce as follows the relation that exists between the variations of volume and pressure of a gas and the heat necessary to produce them.

Resuming the fundamental equation (3), and writing for shortness,

$$R = \frac{p_0 v_0}{273}, \tag{4}$$

and calling T the absolute temperature $273 + t$, this equation may be written,

$$pv = RT. \tag{5}$$

The consequences which follow are these:

1st. If, the pressure p remaining constant, the volume varies by the amount dv, the temperature undergoes a corresponding variation represented by $\frac{pdv}{R}$; and, consequently, the gas has received a quantity of heat $\frac{c'pdv}{R}$, c' being the specific heat under constant pressure.

2d. If, the volume v remaining constant, the pressure varies by dp, the temperature varies by $\frac{vdp}{R}$; and the gas has received a quantity of heat equal to $\frac{cvdp}{R}$, c being the specific heat under constant volume.

3d. Consequently, if the volume and pressure increase together by dv and dp, the gas receives a quantity of heat:

$$dq = \frac{1}{R}(c'pdv + cvdp). \tag{6}$$

Differentiating (5), we have,

$$(7) \qquad RdT = pdv + vdp,$$

and, eliminating successively between (6) and (7) dp and dv, we have the two equations,

$$(8) \qquad dq = cdT + \frac{c' - c}{R} pdv,$$

$$(9) \qquad dq = c'dT - \frac{c' - c}{R} vdp;$$

which, together with (6), contain all the thermodynamic laws of gases.

6. We will first consider equation (8). The quantity pdv, which appears in its second member, is evidently the work done by the elastic force of the gas when the volume increases by dv.

Let ω be an infinitely small element of the surface which incloses the gas. The pressure on this element is $p\omega$, since p is the pressure on unit of surface; and the element of work of this pressure corresponding to an infinitely small increase of volume is $p\omega h$, h being the displacement of ω perpendicular to itself. The work done then is $p\Sigma\omega h$; but $\Sigma\omega h$ is the variation of the volume dv; therefore pdv is the external work done by the gas.

It results, then, from equation (8) that the quantity of heat absorbed by a gas in an infinitely small change is composed of two terms; of which the first is proportional to the change of temperature, and the second to the element of external work.

If we consider a change which alters by finite quantities the temperature and volume of a gas, we derive, by integrating (8), the quantity of heat absorbed during the change:

$$q = \int \left(cdT + \frac{c' - c}{R} pdv \right).$$

If c and c' are functions of T and v, this expression can only be integrated if we know the relation between them; but if we assume (No. 4) that c and c' are constants, we have

$$q = c \int dT + \frac{c' - c}{R} \int pdv,$$

or calling T_0 and T_1 the initial and final temperatures and $\mathfrak{G}$ the total external work done by the elastic force of the gas, we have

$$(10) \qquad q = c(T_1 - T_0) + \frac{c' - c}{R} \mathfrak{G}.$$

6½. *Equivalence of the heat and work.*—If we put $T_1 = T_0$ in the last equation, that is, if the gas returns to its initial state, we have

$$(11) \qquad q = \frac{c' - c}{R} \mathfrak{G}.$$

Thus, in this case, the amount of heat absorbed by the gas is proportional to the external work done.

The quantity

(12) $$A = \frac{c' - c}{R},$$

which expresses the ratio between the heat absorbed and the work done, is called the calorific equivalent of the work; and its reciprocal,

(13) $$E = \frac{R}{c' - c},$$

is the mechanical equivalent of the heat.

We thus see that we may deduce from the known laws which govern gases the notion of the equivalence of heat and work, whose precise conception has led to so great progress in the theory of heat. The fundamental postulate of this theory consists in the assertion that the quantity which has been designated E is invariable, and *independent of the nature of the body* which has served as intermediate in the transformation of heat into work. We need not recall here the reasoning which has established the soundness of this principle, which may otherwise be considered as sufficiently confirmed by the verification of its numerous consequences.

We consider, then, that, for perfect gases, there exists between the volume and the two specific heats the relation expressed by (13); or, taking into consideration the value of R (4), the relation,

(14) $$E = \frac{1}{273} \frac{p_0 v_0}{c' - c}$$

expresses an invariable number, depending solely upon the choice of the units which serve to express the quantities of work and heat.

7. *Value of the mechanical equivalent of heat.*—Since the value of E is independent of the nature of the gas, we may derive it from the values of v_0, c', and c, which have been experimentally determined for many gases, following the laws of Mariotte and Gay-Lussac. We take, for example, atmospheric air.

Regnault's experiments show that under constant pressure the specific heat of air is $c' = .23754$,
and that its specific volume (the reciprocal of the specific weight), taking for units the meter and the kilogram, is

$$v_0 = \frac{1}{1.2932}.$$

Finally, the ratio between the two specific heats, deduced from the velocity of sound as observed by Regnault, is

$$\frac{c'}{c} = 1.3945,$$

from which we derive, for the specific heat of constant volume,

$$c = .17034.$$

Inserting these numerical values in (14) and putting $p_0 = 10333$, we find

$$E = 436. \tag{15}$$

This, then, is the value of the mechanical equivalent of heat, as determined from the best determined constants which are now obtainable. It is the value which we shall adopt. We must not lose sight of the fact, however, that there is some uncertainty as to its exact value, in consequence of the large result that small variations in the value of the ratio $\frac{c'}{c}$ would produce.

8. *Adiabatic transformations.*—Up to this point we have considered only those transformations in the state of a gas which are caused by its losing a quantity of heat. It may, however, happen that the transformation takes place within an envelope which is impermeable to heat; in which case the gas may change its volume and pressure, and consequently its temperature, without gain or loss of heat. The change is then said to be adiabatic, and the laws which govern it may be derived from equations (6), (8), and (9), by putting $dq = 0$. We thus obtain the relations,

$$c'pdv + cvdp = 0, \tag{16}$$

$$cdT + \frac{c' - c}{R} pdv = 0, \tag{17}$$

$$c'dT - \frac{c' - c}{R} vdp = 0; \tag{18}$$

from which follow several important results.

9. *Law of pressures.*—Taking equation (16), and putting $n = \frac{c'}{c}$, it may be written

$$n \frac{dv}{v} + \frac{dp}{p} = 0,$$

whence, integrating, and calling f a constant,

$$n \log v + \log p = \log f,$$

or,

$$v^n p = f. \tag{19}$$

Also v, the volume of the unit of weight, is the reciprocal of ρ, the weight of the unit of volume. Thus, equation (19) may be written $p = f \rho^n$; or, in an adiabatic change, the pressure varies proportionally to a power of the density equal to the ratio of the two specific heats.

Such is the law of pressures discovered by Laplace and Poisson before the birth of the mechanical theory of heat.

10. *Law of temperatures.*—Let us consider equation (17). If we put $c' = nc$, and for p its value $\frac{RT}{v}$ derived from (5), it becomes

$$\frac{dT}{T} + (n - 1)\frac{dv}{v} = 0,$$

whence, by integration, and calling f_1 a constant,

$$Tv^{n-1} = f_1. \tag{20}$$

Consequently, recollecting that, as before, v is the reciprocal of the density, we have this law: *The absolute temperature of a gas, in any adiabatic transformation, is proportional to a power of the density equal to the ratio of the two specific heats minus one.*

We may also present this law under another form. Equation (17) may be written

$$EcdT + pdv = 0,$$

by recollecting that we have, from (13), $\frac{c' - c}{R} = \frac{1}{E}$. Consequently, integrating, and calling T_0 and T_1 the initial and final temperatures of the gas, we have

$$Ec(T_0 - T_1) = \int pdv. \tag{21}$$

But the second member represents the total work done by the elastic force of the gas (No. 5). Thus, in an adiabatic transformation, *the temperature is lowered by a quantity which is proportional to the external work done.*

11. *The work done by the indefinite adiabatic expansion of gas.*—If we suppose that the gas expands indefinitely without gain or loss of heat, the volume v increases indefinitely; and it results, from equation (20), that the temperature T approaches zero. The final temperature of the transformation T_1 is then zero. Putting $T_1 = 0$ in equation (21), we have, for the total work of the expansion,

$$\theta = EcT_0. \tag{22}$$

The work is therefore equal to the product of the mechanical equivalent of heat, the specific heat under constant volume, and the initial absolute temperature.

We may thus say that the measure of this work is found by multiplying the mechanical equivalent of heat by the quantity of heat which the gas absorbs, under constant volume, when its temperature is raised from the absolute zero to T_0; or gives out, under constant volume, when its temperature is lowered from T_0 to absolute zero.

We shall finish this exposition by a rapid summary of the laws which control the volumes and specific heats of gases and vapors,

and which permit us, in many cases, to calculate these important elements without its becoming necessary to have recourse to experimentation.

12. *Laws governing mixtures of gases.*—1st. The specific volume of a mixture of gases is the compound mean of the specific volumes of the gases mixed. Thus, let a_1, a_2, a_3, be the quantities of the various gases which make up a unit of weight of the mixture, and v_1, v_2, v_3, the specific volumes corresponding; the specific volume of the mixture is

$$v_0 = a_1 v_1 + a_2 v_2 + a_3 v_3 + \qquad (23)$$

EXAMPLE.—Taking for units the kilogram and meter, the specific volumes of oxygen and nitrogen are .69941 and .79607. And, according to the determinations of Dumas and Boussingault, these gases exist in atmospheric air in the ratio of .23 to .77. Substituting these values in (23), we have, for the specific volume of atmospheric air, $v_0 = .77385$. Regnault found by direct experiment, $v_0 = .77318$, which differs little from the first.

2d. The specific heat (under constant pressure or constant volume) of a mixture of gases is the compound mean of the specific heats of the gases mixed. This law gives rise to the formula,

$$c = a_1 c_1 + a_2 c_2 + a_3 c_3 + \qquad (24)$$

similar to the foregoing.

If we apply this to the heat of atmospheric air under constant pressure, using the values $c'_1 = .2175$ and $c'_2 = .2438$ for the specific heats of oxygen and nitrogen, we find $c' = .2378$. Regnault's experimental determination was .2374.

13. *Relation between the specific volumes and molecular weights.*—Gay-Lussac was the first to formulate the following important law, which subsequent experimentation has fully confirmed:

The product of the specific volume of a gaseous body by its chemical equivalent, or by a multiple or simple submultiple of this equivalent, is constant.

Thus, if we designate by v_0 and e the specific volume and the equivalent, we have

$$mev_0 = h, \qquad (25)$$

m being a number which is generally unity, sometimes 2 or $\frac{1}{2}$, and very rarely $\frac{1}{4}$.

Taking $m = 1$ for hydrogen, we have:

$m = 1$ for nitrogen, chlorine, bromine, iodine, and all the metals which have as yet been volatilized. To this group belong also numerous binary compounds; protoxide of nitrogen, carbonic oxide, carbonic dioxide, vapor of water, sulphurous acid, hydrogen sulphide, &c.

$m = 2$ for some simple bodies: Oxygen, sulphur, selenium, tellurium, phosphorus, arsenic.

$m = \frac{1}{2}$ for binoxide of nitrogen, chlorhydric acid, ammonia.

$m = \frac{1}{4}$ for some very few substances, chlorhydrate of ammonia, for example.

If we take unity as the equivalent of hydrogen, and take the kilogram and meter as units, the numerical value of h is 11.15, about; so that the specific volume of a gas whose equivalent is e is given by the formula,

$$v_0 = \frac{11.15}{me}. \tag{26}$$

Gay-Lussac's law may be very simply presented, if we admit, following the atomic theory, that the number of molecules in unit of volume, at a fixed pressure and temperature, is the same for all gases. In fact, according to this hypothesis, the weight of unit of volume is proportional to the weight of a molecule, or to the molecular weight. But the weight of unit of volume, and the specific volume v_0, are inversely proportional; hence, from (26), the molecular weight is proportional to me.

Thus, the multiple or submultiple of the equivalent which satisfies the law of the specific volumes is a measure of the molecular weight. For example, the molecular weight of hydrogen and nitrogen being H and N, those of oxygen and sulphur are O^2 and S^2. The molecular weight of ammonia and chlorhydrate of ammonia, for which the values of m are $\frac{1}{2}$ and $\frac{1}{4}$, are $N^{\frac{1}{2}}\ H^{\frac{3}{2}}$ and $N^{\frac{1}{4}}\ HCl^{\frac{1}{4}}$.

We may thus formulate as follows the law of specific volumes: *The product of the specific volume of a gas by its molecular weight is constant.*

14. *Laws of specific heats.—Molecular heat.*—The product of the molecular weight of a body by its specific heat is called the molecular heat of the body.

Regarding gases we have from experiment:

1st. That the molecular heat under constant pressure has the same value, K', for hydrogen, nitrogen, and oxygen.

2d. That it is greater than K' for the other gases and vapors, and that it becomes greater as the gas becomes more complex.

The numerical value of K', derived by taking the mean of the specific heats of hydrogen and nitrogen, may be taken as 3.411.

If, then, we call c' the specific heat under constant pressure and ω the molecular weight, we may write,

(27) $$c' = \frac{K' + a}{\omega},$$

a being a quantity which is equal to zero for the simple gases, and those the nearest to the state of a perfect gas; and is positive for others, and increases as the molecule of the gas or vapor is made up of a larger number of atomic elements.

For example, for vapor of water, carbonic sulphide, alcohol, and ether, whose molecular weights are

$$HO \quad CS^2 \quad C^2H^3O \quad C^4H^5O,$$

the values of a are respectively

$$.913 \quad 2.555 \quad 7.017 \quad 14.386.$$

15. The specific heat under constant volume, whose experimental determination is almost impossible, is calculated for perfect gases by the relation (14), which gives

(28) $$c = c' - \frac{1}{273}\frac{p_0 v_0}{E}.$$

It is only necessary to know c' and the specific volume v_0. The latter may be determined by experiment, or deduced from formula (26), when the molecular weight ω is known. We have, in this case, $v_0 = \frac{h}{\omega}$; and consequently putting

(29) $$K = K' - \frac{1}{273}\frac{p_0 h}{E},$$

and replacing c' by its value (27) in equation (28), the latter may be written,

(30) $$c = \frac{K + a}{\omega}.$$

The value of K, the molecular heat under constant volume of simple perfect gases, is obtained from numerical values of quantities on which (29) depends.

We have already shown that

$K' = 3.411 \qquad h = 11.15 \qquad E = 436 \qquad p_0 = 10333,$

whence it results $K = 2.443$.

16. *Relation between the two specific heats.*—This ratio, which is so important a factor in all adiabatic transformations, is deduced from (27) and (30); which give

(31) $$n = \frac{c'}{c} = \frac{K' + a}{K + a}.$$

For hydrogen, nitrogen, and oxygen we have, very nearly, $a = 0$; consequently

$$n = \frac{K'}{K} = \frac{3.411}{2.443} = 1.40, \text{ nearly.}$$

For gases and vapors whose molecules are complex, the value of n approaches rapidly to unity for increasing values of a.

If we admit, for example, the values of a already given (No. 14), we have, for vapor of water, sulphur, carbon, alcohol, and ether:

$$n = 1.29 \qquad 1.19 \qquad 1.10 \qquad 1.06.$$

17. Finally, the value $n = 1.40$, which we have found for those of the simple gases which approach most nearly the ideal state which has been called the state of a perfect gas, appears itself inferior to the theoretical limit which would be realized if the molecules of the gas were strictly mono-atomic. It results, in fact, from reasoning based on the new thermodynamic theory, that the ratio of the two specific heats has in this case the extreme value $n = \frac{5}{3}$. The smaller value (1.40) found is explained by Gehrard and Clausius by the hypothesis that the molecules of even these gases contain at least two atoms.

We are thus led to conclude that the ratio of the two specific heats, variable with the greater or less complexity of the body, is between the limits $\frac{5}{3}$ and 1; and approaches rapidly to the inferior limit when the number of atoms making up the molecule is increased. We shall see hereafter that these considerations, which may appear at first purely speculative, are not without importance for the particular object in view.

18. *Hypothetical law of Clausius.*—It is known from experiments of Regnault upon the specific heats of solids that:

1st. The molecular heat of simple bodies is constant (Dulong and Petit's law).

2d. The specific heat of compound bodies is the compound mean of that of the simple bodies of which they are composed.

Clausius supposes that these two laws may be applied to the specific heats under constant volume of perfect gases. According to this hypothesis the specific heat under constant volume of a perfect gas may be found by the relation,

$$c = \frac{K}{\omega}, \tag{32}$$

ω being its molecular weight and K the constant, whose definition and value have already been given (No. 15).

19. The specific heat of a compound gas is deduced, by formula (24), from its chemical composition, *as if the combined elements were mixed.* If, for example, a gas whose composition is represented by the formula

$$\omega_1^{n_1} \quad \omega_2^{n_2} \quad \omega_3^{n_3},$$

ω_1, ω_2, ω_3 being the molecular weights of the constituents, so that

$$\omega = n_1\omega_1 + n_2\omega_2 + n_3\omega_3$$

will be the molecular weight of the compound. We apply here formula (24), remarking that the quantities of the elements in unit of weight of the compound are

$$a_1 = \frac{n_1\omega_1}{\omega}, \qquad a_2 = \frac{n_2\omega_2}{\omega}, \qquad a_3 = \frac{n_3\omega_3}{\omega}.$$

Consequently, calling c_1, c_2, c_3, the specific heats under constant volume of the constituents, and c that of the compound, we have

$$c = \frac{n_1\omega_1 c_1 + n_2\omega_2 c_2 + n_3\omega_3 c_3}{\omega},$$

and finally, from the relation (32),

$$c = \frac{K(n_1 + n_2 + n_3)}{\omega}. \tag{33}$$

Putting $n_1 + n_2 + n_3 = N$, and putting $v_0 = \frac{h}{\omega}$ and $c = \frac{KN}{\omega}$ in equation (28), and from (29) we have,

$$c' = \frac{K' + (N - 1)K}{\omega}. \tag{34}$$

From (33) and (34) we have, finally,

$$n = \frac{c'}{c} = 1 + \frac{1}{N}\left(\frac{K'}{K} - 1\right); \tag{35}$$

which, from the value $\frac{K'}{K} = 1.40$, already found (No. 16), for perfect simple gases, may be written in the very simple form,

$$n = 1 + \frac{2}{5N}. \tag{36}$$

20. It is hardly necessary to dwell upon the importance of the preceding formulas. They show that the specific heats of gases and vapors depend upon their chemical composition.

The application of these formulas, even to perfect gases, must, however, be under certain reservations. For if, as shown by the experiments of Regnault, hydrogen, nitrogen, and oxygen satisfy sufficiently accurately (32), it is not so for chlorine and bromine; and the departures from the law are sufficiently great to make us attribute them to something else than alterations in the laws of Mariotte and Gay-Lussac.

Also, formula (33) gives greater values to the specific heats of compound gases than those found by experiment. In this last case, however, the error must be lessened at high temperatures; for the specific heats under constant pressure of imperfect gases increases with the temperature, as Regnault has shown by experiment upon carbonic acid.

If it is not, then, certain that the hypothesis of Clausius gives rigorous formulas in the limiting state, we can at least admit that it furnishes an approximation equally good with that furnished by the experimental laws which govern the specific heats of simple and compound solids; and that the relations which are derived from it, so frequently used by Berthelot in his researches in thermo-chemistry, may be reasonably accepted.

We shall apply them in the following chapter to the theoretical calculation of the principal elements which are required for the approximate evaluation of the force of explosive substances.

CHAPTER II.

On the Force of Explosive Substances.

1. When a substance is exploded in a capacity of constant volume, the products of combustion develop a pressure whose value, variable with the time, reaches a maximum in an extremely short space of time, and then decreases progressively in consequence of cooling. At the end of this cooling the substance is changed into products whose nature is variable with the conditions of the explosion, and which may be determined by chemical analysis.

These products are, according to circumstances:

Exclusively gaseous (detonation of chloride of nitrogen); gaseous and solid (explosives of the nitrate and chlorate class); gaseous and liquid (nitro-glycerine and gun-cotton).

In all cases we must admit that, at the instant of maximum tension, the products are totally gasified; the temperature at this instant is generally greater than the melting point of the most refractory metals.

Also, at this temperature, the products of combustion are probably not the same as those found after the cooling. As remarked long since by Melsens, they are then partially or totally dissociated; and, by a chain of transformations producing gradually less simple combi-

nations, the variable state of temperature and pressure brings about the final state, which alone can be the subject of observation.

2. *Force of an Explosive Substance.*—If we suppose that the laws of Mariotte and Gay-Lussac are applicable to the gasified products of explosion at the instant of maximum tension, the value of this tension, as a function of the temperature and specific volume corresponding, is easily obtained.

Suppose, for example, that we consider unit of weight of an explosive detonating in volume v. The maximum pressure will be given by the equation

$$pv = \frac{p_0 v_0 T_0}{273}, \tag{37}$$

in which T_0 is the absolute temperature of the products of explosion at the instant of maximum tension; v_0 the specific volume of the mixture of these products, supposed entirely gasified.

Consequently, we have the pressure, which is inversely proportional to the volume, equal to $\frac{p_0 v_0 T_0}{273}$, when the volume is reduced to unity.

The quantity

$$f = \frac{p_0 v_0 T_0}{273} \tag{38}$$

is what we shall call the force of the explosive. It represents *the pressure developed by the unit of weight of the substance detonating in unit of volume.*

We shall next see how its approximate value may be determined.

3. *Heat and Temperature of Combustion.*—We shall call heat of combustion the quantity of heat Q that unit of weight of the explosive substance evolves, under constant volume, in the ideal case where the final temperature of the products of combustion is absolute zero.

The absolute temperature of combustion is the temperature T, which the products would have if all the heat of the combustion were used to heat them from absolute zero.

If the specific heat of the products of combustion under constant volume were constant throughout the transformations which these products undergo in passing from absolute zero to T, or, inversely, from T to absolute zero, we would have between Q and T the well-known relation

$$T = \frac{Q}{c}. \tag{39}$$

The specific heat, c, would be practically constant if, in the changes undergone, the products remained gaseous, and if, in this state, the hypothesis of Clausius were really applicable to them. In fact the specific heat of a compound gas being, according to this hypothesis, the same as if the combined elements were mixed, it is clear that the mean specific heat of the mixture preserves, in all states, a value equal to that of the entirety of the simple bodies which make up the explosive body, supposed freely mixed.

In reality, there is reason to believe (Chapter I, No. 14) that this is only approximate, and that the specific heat increases in transformations in which the constituents pass from a less to a greater state of complexity. It also certainly increases at the time of the passage of a body from the gaseous to the liquid state, and from the liquid to the solid state.

Consequently, equation (39) would give too great a value for T, if we take for c a value derived by the hypothesis of Clausius for the entirety of the products supposed gaseous. We would have too small a value on the other hand if we follow Bunsen and Schisckhoff, and take the value relative to the final state.

We shall adopt the first value, which, as Berthelot has remarked, seems to be preferable for reactions whose temperatures are high, and which, moreover, has the advantage of enabling us to calculate the value *a priori* from the composition of the explosive substance and independently of an analysis of the products of explosion.

4. We shall suppose also, following all the authors who have treated subjects analogous to the one we have in view, that the temperature, T_0, corresponding to the maximum pressure, is sensibly equal to the temperature of combustion, T, already defined. We write, consequently,

$$T_0 = \frac{Q}{c}. \tag{40}$$

Thus we have a superior limit; for the heat of combustion, Q, comprises not only the quantities of heat which change the temperature of the products, but also those which the chemical or physical changes of state produce.

These principles being admitted, we obtain the definite expression of the force of an explosive substance in this form,

$$f = \frac{1}{273} \cdot \frac{p_0 v_0 Q}{c}. \tag{40½}$$

The force, then, *is directly proportional to the heat of combustion and the specific volume, and inversely proportional to the specific heat.*

It remains now to show how these three characteristic elements may be theoretically or experimentally determined.

5. *Value of the specific heat under constant volume.*—According to the hypothesis which has been admitted, the value of c is obtained by applying the law of gaseous mixtures (Chapter I, No. 12) to the elements which make up the substance under consideration.

If, for example, a_1, a_2, a_3, are the proportions of the various elements, and ω_1, ω_2, ω_3, their molecular weights, for unit of weight, the corresponding specific heats are, according to equation (32),

$$\frac{K}{\omega_1}, \quad \frac{K}{\omega_2}, \quad \frac{K}{\omega_3},$$

and we have, consequently, according to formula (24), for the specific heat sought,

$$c=K\left(\frac{a_1}{\omega_1}+\frac{a_2}{\omega_2}+\frac{a_3}{\omega_3}+\ldots\right) \tag{41}$$

This formula requires that the molecular weight of the elements shall be known. The following are the values for those simple bodies which make up the most common explosives:

Name of body.	Molecular weight. Symbol.	Molecular weight. Value.
Hydrogen	H	1
Nitrogen	N	14
Chlorine	Cl	35.5
Oxygen	O^2	16
Sulphur	S^2	32
Carbon	C^2	12
Potassium	$K^{\frac{1}{2}}$	19.5
Sodium	Na^1	11.5

6. Another method may be given for the calculation of c. Suppose, first, that the substance is a definite compound, like nitroglycerine or gun-cotton; and that its equivalent e is represented by the formula $\omega_1^{n_1}\,\omega_2^{n_2}\,\omega_3^{n_3}$; ω_1, ω_2, ω_3, being the molecular weights of the elements, so that we have

$$e=n_1\,\omega_1+n_2\,\omega_2+n_3\,\omega_3+$$

The proportions of the elements in unit of weight being

$$a_1=\frac{n_1\,\omega_1}{e}, \quad a_2=\frac{n_2\,\omega_2}{e}, \quad a_3=\frac{n_3\,\omega_3}{e},$$

formula (41) becomes

$$c=\frac{K(n_1+n_2+n_3+\ldots)}{e}. \tag{42}$$

Notice that, in this expression, as well as in the equivalent one (41), the numerical value of K is (Chapter I, No. 15),

$$K = 2.443.$$

Let us take, for example, chloride of nitrogen, NCl^3; we have

$$e = 14 + 3 \times 35.5 = 120.5,\ n_1 = 1,\ n_2 = 3,\ c = \frac{2.443 \times 4}{120.5} = .0811.$$

Again, let nitro-glycerine be represented by the formula

$$C^6H^2(NO^6H)^3 = C^6H^5N^3O^{18};$$

in this case, $e = 227$.

Writing the formula in the form

$$(C^2)^3H^5N^3(O^2)^9,$$

in order to show the molecular weights, we have

$$c = \frac{2.443\,(3 + 5 + 3 + 9)}{227} = .2197.$$

7. When the substance is a mixture we may first calculate the specific heat for each of the constituents, and then take the compound mean according to the proportions of the ingredients.

The following table shows the values of c for the simple and compound bodies which compose the principal explosives:

Name of substance.	Equivalent.	Value of c.
Sulphur	S	.0763
Carbon	C	.2036
Nitrate of potassium	NO^5KO	.1451
Nitrate of sodium	NO^5NaO	.1724
Chlorate of potassium	ClO^5KO	.1197
Chloride of nitrogen	NCl^3	.0811
Nitro-glycerine	$C^6H^2(NO^6H)^3$	.2197
Gun-cotton	$C^{24}H^{10}O^{10}NO^6H^5$	.2314
Picrate of potassium	$C^{12}H^2K(NO^4)^3O^2$	.1830

The following are the values of c for the various powders made in France:

Kind of powder.	Mixture. Nitre.	Sulphur.	Charcoal.	Value of c.
Best sporting powder	78	10	12	.1452
Cannon powder	75	12.5	12.5	.1437
Fine-grained powder, called 1 B	74	10.5	15.5	.1468
Powder of commerce	72	13	15	.1448
Ordinary blasting powder	62	20	18	.1420

These values differ very little, and may all be taken as equivalent to their mean, .1445.

It has also been found that for a mixture of 55 parts of picrate of potassium and 45 of saltpetre, $c = .1661$; and, for a mixture of equal weights of picrate and chlorate of potassium, $c = .1513$.

NOTE.—In the calculations relative to gunpowder the charcoal has been treated as pure carbon. The charcoal used in the manufacture of gunpowder contains, however, hydrogen and oxygen about in the proportion in which they exist in water. This will cause an increase in the value of c, and one which may become appreciable, since the value of c for vapor of water is .4072.

9. *Theoretical determination of the heat of combustion.*—The heat of combustion, which, like the specific heat, is one of the characteristic elements of the force of explosive substances, may be calculated when we know:

1st. The chemical composition of the substance and the final products.

2d. The quantities of heat absorbed or given out by the formation of the compounds which make up the initial and final state of the reaction.

It results, in fact, from one of the fundamental laws of thermo-chemistry, that the amount of heat given out by a continuous series of reactions is equal to the difference between the heat of formation of the compounds in the initial and final states.

Berthelot, who was the first to state this law, basing it upon the well-known law of the conservation of energy, has made numerous and important applications of it to the heats of combustion of explosive substances. It is thus made possible, by studying the calorimetric researches of various experimenters, and, without making further determinations, to explain in a rational manner the characteristic properties of the detonating substances, which, before the utterance of this law, could be compared only by empirical methods.

We shall not dwell further upon these interesting researches, but, referring the reader to the works of that eminent chemist for further details, shall recall some experimental laws which bear upon the same subject.

9. *Experimental determination of the heat of combustion.*—To determine by experiment the heat of combustion of an explosive substance we have only to fire a known weight of it in a vessel plunged in a calorimeter, and to observe the increase of the temperature of the bath when it has absorbed the heat of the reaction.

The first determination of this nature was made by Bunsen and Schischkoff upon a powder like our sporting powder. The experiment showed that the products of combustion of a kilogram of this powder give out 644 *calories* in cooling to a temperature of 20 degrees.

We have attempted, in a series of experiments at the central depot of the State manufactory, to resume these researches, and to extend them to various substances. We shall give, further on, the results of these experiments.

Calorimetric determinations do not give all the heat of combustion, Q. The measured quantity, q, is that which is given out by the products of combustion in passing from the temperature of combustion, T, to the absolute temperature of the calorimeter t. The difference, $Q-q$, represents, then, the heat which would be given up in passing from t to absolute zero. It is generally very small, compared to Q, because of the extreme elevation of the temperature of combustion. We may, moreover, easily find its value if we know the specific heat, c, between the limits of t and zero. We would have,

$$Q = q + ct. \tag{43}$$

The specific heats corresponding to the lower temperatures are, in general, not known; for the want of more precise data, we may substitute for them the theoretical values found in No. 7. These values are too small; but the resulting error, affecting only a relatively very small term, would be small. The mean temperature of our experiments being 17 degrees, the corresponding value of the absolute temperatures is $t = 273 + 17 = 290$.

We may thus, for these elements, approximately correct the observed heats, and derive from them the corresponding heats of combustion.

The following table gives, for the principal explosives:

1st. The quantity of heat q, measured by the calorimeter;

2d. The heats of combustion Q, deduced from the foregoing by (43);

3d. The temperatures of combustion, calculated from the heats of combustion Q, and the theoretical specific heats by the formula $T = \frac{Q}{c}$.

Name of explosive.	Heat of combustion. Measured. q. Calories.	Heat of combustion. Corrected. Q. Calories.	Temperature of combustion. Degrees cent.
Best sporting powder, ...	807	849	5870
Cannon powder, ...	553	795	5500
Fine-grained powder, called B, .	731	773	5350
Commercial powder, ...	694	736	5090
Ordinary blasting powder, . .	570	612	4240
Chloride of nitrogen, ...	16	339	4180
Nitro-glycerine, ...	1720	1784	8120
Gun-cotton, ...	1056	1123	4850
Picrate of potassium, ...	787	840	4590
Mixture of 55 picrate of potassium and 45 saltpetre, ...	916	964	5810
Equal parts of picrate and chlorate of potassium, ...	1180	1224	8090

These figures are the results of calorimetric experiments made at the central depot, except those for the heat of combustion of chloride of nitrogen, which were made by Deville and Hautefeuille.

10. *Theoretical determination of the specific volume* v_0.—The specific volume of the products of combustion presents greater difficulty in its determination than any other of the elements. For we can only observe the products in their final state, and can know nothing experimentally of their condition at the instant of maximum tension. We can, however, make a calculation according to two hypotheses, corresponding to two extreme cases which comprise, probably, the truth.

We can make the calculation as though the elements of the mixture were entirely dissociated, having thus a superior limit of the possible specific volumes; and we have also an inferior limit by supposing that the compounds found in the final state are already formed, and are simply vaporized at the time of maximum tension.

First case. *Complete dissociation.*—Resuming the notation of No. 5, let us call $a_1, a_2, a_3, \ldots$ the proportions of the elements forming unit of weight of the substance, and $\omega_1, \omega_2, \omega_3, \ldots$ their molecular weights. The corresponding specific volumes are (Chapter I, No. 13)

$$v_1 = \frac{h}{\omega_1}, \quad v_2 = \frac{h}{\omega_2}, \quad v_3 = \frac{h}{\omega_3},$$

and the specific volume of the mixture is, by (23),

$$v_0 = h\left(\frac{a_1}{\omega_1} + \frac{a_2}{\omega_2} + \frac{a_3}{\omega_3} + \ldots\right) \tag{44}$$

Second case. *Vaporization of the final products.*—If the final products have been found by chemical analysis, the specific volume of each one may be calculated from its molecular weight, which, generally, is equal to its equivalent. This computation involves no other possible error than the one which results from our being obliged, in certain cases, to take the half of the equivalent. The cases in which the molecular weight is one-fourth of the equivalent are very exceptional, and may be left out of account.

After the preliminary calculation, it is only necessary to take the mean of the specific volumes of the bodies forming the final state according to the proportions of the mixture.

11. The calculation is simplified by applying first the equivalent of the explosive substance, and afterwards reducing to unit weight. If the composition in the final state is known, in equivalents, the specific volumes in the two limiting cases may be simply calculated at the same time. Suppose, for example, that the explosive is represented by the formula $\omega_1^{n_1}\,\omega_2^{n_2}\,\omega_3^{n_3}\,\ldots$; ω_1, ω_2, ω_3, being the molecular weights of the elements, so that

$$e = n_1\,\omega_1 + n_2\,\omega_2 + n_3\,\omega_3 + \ldots$$

is the equivalent of the substance.

Call ϖ_1, ϖ_2, ϖ_3, . . . the molecular weights of the bodies of the final state, and

$$e = N_1\varpi + N_2\varpi_2 + N_3\varpi_3 + \ldots$$

the formula of the reaction.

Reasoning as we have already done several times, particularly to obtain formula (42) for the specific heats, we easily find that the specific volume is represented by the formula

$$v_0 = \frac{h\,(n_1 + n_2 + n_3 + \ldots)}{e}, \tag{45}$$

in the case of *entire dissociation;* and by the formula

$$v_0 = \frac{h\,(N_1 + N_2 + N_3 + \ldots)}{e}, \tag{46}$$

in the case of the *volatilization of the compounds of the final state.* The value of h is (Chapter I, No. 13), $h = 11.15$.

12. We consider, for example, nitro-glycerine, whose combustion is represented by Berthelot by the equation

$$C^6H^2(NO^6H)^3 = 6CO^2 + 5HO + 3N + O,$$

or, showing better the molecular weights,

$$(C^2)^3H^5N^3(O^2)^9 = 6CO^2 + 5HO + 3N + \tfrac{1}{2}O^2.$$

Consequently, the specific volume is,

$$v_0 = \frac{11.15\,(3+5+3+9)}{227} = .983,$$

in the case of complete dissociation; and

$$v_0 = \frac{11.15\,(6+5+3+\frac{1}{2})}{227} = .712,$$

in the case of the vaporization of the bodies of the final state.

In the following table are written the calculated results for some explosive bodies. The formulas of reaction adopted are those used by Berthelot in his researches:

Name of explosive.	Specific volume. Of elements dissociated.	Specific volume. Of products volatilized.
Best sporting powder,	.654	.308
Chloride of nitrogen,	.370	.370
Nitro-glycerine,	.983	.712
Gun-cotton,	1.056	.680
Picrate of potassium,	.835	.669

13. *Intermediate states.*—We see, from the table, how great an influence the chemical state of the products at the instant of maximum tension has upon the value of the specific volume. The ratio of the two limits, which is unity for chloride of nitrogen, which always decomposes into its simple elements, varies for the different bodies between that limit and two, for the best sporting powder.

Now, between these two extreme cases, there may be intermediate states, according to the varying physical conditions of the products in the very short period between the beginning of the burning and the instant of maximum tension. It is very probable that the mode of combustion may exercise a very great influence on these circumstances; and that the conditions, for example, which develop the reaction instantly in all parts of the body, differ essentially, from this point of view, from those which cause a progressive reaction.

It is probable that we may ascribe to these causes the different effects produced by the same substance under varying conditions.

14. *Theoretical calculation of the force of an explosive substance, when totally dissociated.*—Following our examination of the circumstances on which the characteristic elements of explosive substances depend, we may lay down some considerations regarding the theoretical expression for the corresponding force.

This expression is given by formula ($40\frac{1}{2}$), and its value may be

found when, by the aid of the preceding principles, the values of c, Q and v_0 are known. Among the results which are thus obtained, we must notice that which relates to the complete dissociation of the products of combustion.

In this case, according to the values of c and v_0 (41) and (44), the formula reduces to

$$f = \frac{p_0}{273} \frac{hQ}{K}, \tag{47}$$

and, as the constants h and K are independent of the nature of the substance, we are led to the following consequence: *The force of an explosive substance when entirely dissociated, is proportional to its heat of combustion.*

We have, also, $h = 11.15$, and $K = 2.443$; inserting these values in (47), and putting $p_0 = 1$, we have for the expression of the force in atmospheres,

$$f = .01672 \times Q. \tag{48}$$

This is evidently a limit superior to that actually reached.

15. *Intermediate states—Equivalent combustions.*—There is reason to suppose, as has already been stated, that the chemical state of the products at the instant of maximum tension is not generally that of complete dissociation; the actual state is less simple and varies with the conditions of combustion.

Among the different reactions which these conditions may cause, we note those which present the same initial and the same final states. To these reactions the following principle, laid down by Berthelot, in his thermo-chemical researches, under the name of the "principle of the calorific equivalence of chemical transformations," applies:

Having given a system of simple or compound bodies in a determined state; if this system undergoes any physical changes bringing it to a second state, the quantity of heat absorbed or given out depends solely upon the initial and final states of the system. It is the same, whatever may be the nature or sequence of the intermediate states.

Let us call, for brevity, those reactions which have the same initial and final states, *calorifically equivalent*, or simply *equivalent* reactions.

Observing that:

1st. Equivalent reactions have the same heat of combustion Q;

2d. The specific heat of differing equivalent reactions is the same, since, according to the hypothesis of No. 3, it depends only upon the nature and proportions of the simple elements present in the reactions.

Thus the force varies only as the specific volume v_0; and we have this consequence:

The force developed by the same explosive substance, in varying equivalent reactions or combustions, is proportional to the specific volume of the products formed at the instant of maximum tension.

By the different values of this element, variable with the state of dissociation of the products, may be explained the considerable variations of the force; even though chemical analysis of the final products and calorimetric determinations remain the same.

16. *Theoretical calculation of the force of the final products when vaporized.*—The lower limit of the force of an explosive is obtained by the aid of the value of v_0, corresponding to the final state of the products, supposed entirely gasified, but not decomposed, at the instant of maximum tension.

Making the calculation for the substances whose specific volume has already been found (No. 12), and comparing them with those which are obtained by the formula for total dissociation, we have the following table:

Name of explosive.	Force. Substance dissociated.	Force. Final state vaporized.
Sporting powder,	14.19	6.62
Chloride of nitrogen,	5.67	5.67
Nitro-glycerine,	29.83	21.18
Gun-cotton,	18.78	12.08
Picrate of potassium,	14.04	11.25

The linear unit adopted being the meter, the table gives, in atmospheres, the pressure developed by a kilogram of the substance detonating in a cubic meter.

17. *Approximate expression for the force of an explosive substance.*—We may obtain another expression for the force of an explosive substance. It is only approximate, but is extremely simple, and has the advantage of containing only quantities which may be determined by direct experiment, without its being necessary to have recourse to the determination by chemical analysis; which, as the foregoing considerations show, depends upon the theoretical and somewhat unreliable values of the specific volumes.

Take the general expression for the force,

$$f = \frac{1}{273} \frac{p_0 v_0 Q}{c}.$$

From equation (14), which is between the heat and specific volume of a gas, we find

$$\frac{1}{273}\frac{p_0 v_0}{c} = E\left(\frac{c'}{c} - 1\right).$$

Consequently, calling n the ratio $\frac{c'}{c}$ of the two specific heats, we have the very simple formula,

(49) $$f = (n - 1)\, EQ.$$

The ratio n is equal to 1.40 about for hydrogen, nitrogen, oxygen, carbonic oxide, etc. We have, consequently,

(50) $$f = \frac{2}{5} EQ,$$

if these gases, or others approaching nearly the state of a perfect gas, were the only products of combustion. But, in a great many cases, these products comprise besides vapor of water and other even more complex vapors, which are liquefied or solidified after the cooling. For these compounds, n is less than 1.40, and approaches unity, in consequence of the progressive formation of the final state.

If, then, we call ε the weight of permanent gas due to the combustion of a kilogram of the explosive substance, the quantity $n - 1$ may, in a first approximation, be considered as a function of ε, which, vanishing with ε, becomes $\frac{2}{5}$ for $\varepsilon = 1$. We have then, nearly, $n - 1 = \frac{2}{5}\varepsilon$; and consequently,

(51) $$f = \frac{2}{5} EQ\varepsilon.$$

This formula shows that, similarly to a law of Berthelot, the force of explosive substances is nearly proportional to the product of the heat of combustion by the weight of the permanent gases produced by the explosion.

If the conditions of the explosion are such that the substance is entirely, or even partially, dissociated, so as to produce compound gases for which we would have $n = 1.40$, as would be the case for carbonic oxide, we must take $\varepsilon = 1$, and the force would be given by (50). The latter agrees, as may easily be shown, with the value (47) already obtained.

18. By means of experiments made at the central depot, ε has been determined for some substances. These together with the heats of combustion, and the corresponding forces, expressed in atmospheres, are tabulated below:

Name of explosive.	Weight of gas. ϵ. *Kil.*	Heat of combustion. Q. *Cal.*	Force. f. *Atm.*
Sporting powder,	.337	849	4.83
Common powder,	.412	795	5.53
Fine-grained powder, called B,	.414	773	5.40
Powder of commerce,	.446	736	5.54
Ordinary blasting powder,	.499	612	5.15
Chloride of nitrogen,	1.000	339	5.72
Nitro-glycerine,	.800	1784	24.09
Gun-cotton,	.853	1123	16.16
Picrate of potassium,	.740	840	10.49
55 parts of picrate of potassium and 45 of saltpetre,	.485	964	7.89
Equal parts of picrate and chlorate of potassium,	.466	1224	9.63

19. *Relative force of the explosive substances.*—It is remarkable that the five powders should have about the same force, notwithstanding differences of fabrication. This result has been confirmed by experiment, which shows that the bursting charges of the five different powders for the same shell varies only 15 to 17 grams.

The mean of the forces of powders is 5.29. This corresponds to a force of 5290 atmospheres for a kilogram of powder, detonating in a liter, that is to say, in its own volume; these results are thus in accord with those made by Captain Noble upon powder exploded in its own volume. The pressure measured by him under these conditions by means of a gauge, was 37 tons on the square inch, or 5600 atmospheres, for the F. G. powder, and about 32 tons for the R. L. G. The following table shows the relative force of the different explosives:

Name of explosive.	Relative force.
Powder containing saltpetre,	1.
Chloride of nitrogen,	1.08
Nitro-glycerine,	4.55
Gun-cotton,	3.06
Picrate of potassium,	1.98
55 parts picrate of potassium and 45 of saltpetre,	1.49
Equal parts picrate and chlorate of potassium,	1.82

20. The figures of this table appear to agree sufficiently well with the real effects of explosives, fired in a manner to produce what, in the experiments undertaken with M. Roux, we have called explosions

of the second order, that is to say, explosions produced by any other agency than a strong fulminating primer.

For example, the relative force of gun-cotton is about equal to that found by the French commission on gun-cotton (3.20), derived from the comparison of the charges just necessary to burst a shell.

Other similar experiments confirm the result for nitro-glycerine. The mean charge of powder required to rupture shell was 16 grams. In the same shells, the effect of dynamite which contained 50 per cent. of nitro-glycerine, fired by a small quantity of powder, was such that 1 part of nitro-glycerine was equal to 2 parts of powder, under these circumstances. But, as Berthelot has remarked, the heat disengaged by firing dynamite is divided between the products of the explosion of the nitro-glycerine and the inert vehicle, which latter has about the same specific heat. It results that, in such dynamite, the temperature, and consequently the force, must be lowered one-half. The force of pure nitro-glycerine should then be doubled, and be estimated at about 4. The difference between this value and that given in the table is not great. We will add that, for a mixture of picrate and nitrate of potassium, the bursting charge was found to be about 11 grams, which corresponds to a relative force of $\frac{16}{11} = 1.45$; which differs little from the theoretical value, 1.49.

21. *On the relative force of some substances, when dissociated.*—In applying formula (51) to nitro-glycerine and gun-cotton, we suppose that those of the products which are not permanent gases after the cooling, are vaporized, but not dissociated, at the instant of maximum tension. If they are, on the other hand, decomposed into gas so that the value of n is 1.40, we must use formula (50). In comparing, as before, the new values with the mean force of powder, we obtain the following relative forces:

Nitro-glycerine, ...	5.68
Gun-cotton, ...	3.58

In these new conditions, then, the force of gun-cotton becomes almost four times that of powder.

As to the figure for nitro-glycerine, it appears to have been almost reached in an experiment made by M. Roux, where about 2.7 grams of pure nitro-glycerine were fired by 1 gram of powder in an ordinary shell. In this experiment, 2.7 grams of nitro-glycerine equalled 15 grams of powder; whence the value of the relative force is 5.55, which differs little from its theoretical value, 5.68.

22. *Explosions of the first order.*—But, however great the power

of dissociated nitro-glycerine may be, it still fails to account for the effects observed when this substance is fired by violent percussion or by a charge of fulminate of mercury. It results, in fact, from our experiments, that the effect of nitro-glycerine is then at least nine times that of powder.

We have proved, by a new calorimetric experiment, that the heat disengaged under these circumstances does not differ sensibly from that due to explosions of the second order. Though this proof, made upon a small quantity of dynamite, on account of the intensity of the effects produced, has not the precision of our former determinations; it excludes the possibility of ascribing the great variation in the effects produced to variations in the heats of combustion. We may add that formula (50) being applicable to the complete dissociation of the substance, we cannot suppose that the explosion of the first order can produce new decompositions into simpler elements.

We must, then, either give up the attempt to explain the phenomena by Mariotte's and Gay-Lussac's laws, of which formula (49) is a rigid deduction; or suppose that n, the ratio of the two specific heats, acquires, at the instant of maximum tension, a greater value than 1.40; this latter value is that corresponding, in normal conditions, to simple gases, near the state of a perfect gas. If, adopting this view, we seek to determine a value of n which will make the force of nitro-glycerine nine times that of powder, according to the equation,

$$(n - 1)EQ = 9 \times 5.29 \times 10333,$$

we find, taking for Q the value of nitro-glycerine, 1784,

$$n = 1.632.$$

This value of n, almost equal to $\frac{5}{3}$, reaches, then, the upper limit found theoretically for mono-atomic gases (Chapter I, No. 17).

By pushing further the deductions from this result, we would be led to explain the observed effect by supposing that, under the influence of a violent commotion there may be produced, in certain substances, an unstable molecular structure, a sort of intra-molecular dissociation, capable of destroying, during an infinitely short space of time, the atomic equilibrium, and of causing separation into more simple elements than those which are produccd by the normal mechanism of the internal forces.

We do not disguise the hypothetical nature of these theories; we have thought it better to formulate them, in the absence of better explanation, in order to show that these obscure phenomena are not absolutely inexplicable in the present state of science.

23. If our explanation is correct, and if other unstable nitrogenous compounds, such as chloride of nitrogen and gun-cotton, can experience, like nitro-glycerine, this *atomic dissociation* when violently detonated, the corresponding force will be obtained by putting $n = \frac{3}{5}$ in formula (50). It is then represented by the expression

$$f = \tfrac{3}{5} EQ, \tag{52}$$

and its value is, consequently, $\frac{3}{5}$ of that which is produced in the case of *molecular dissociation*.

The relative forces calculated by this formula are

Chloride of nitrogen,	1.80
Nitro-glycerine,	9.49
Gun-cotton,	5.97

Under these conditions then, chloride of nitrogen will produce double the effect of gunpowder; and this result is certainly not at variance with what we know of the violence of this substance.

24. The foregoing considerations seem likely to throw some light upon the cause of the varying effects produced by explosives according to the manner of their inflammation. They constrain us to admit, for each substance, the existence of a sort of scale of pressures; the point of which reached by the explosive, when the circumstances of the combustion are progressively varied, corresponds to so many sudden variations of the law of tensions.

Nitro-glycerine offers a striking example of this. Its explosive force reduced in the proportion of 5 to 3, when the detonation ceases to be "fulminante," is still more greatly lowered when the cooling of inert bodies suppresses the dissociation of a part of the products of combustion. Do these characteristic effects of the definite explosive compounds appear in the same degree in the combustion of the mixtures which make up the ordinary gunpowders?

Although these substances have a relative stability, it is probable that they produce analogous phenomena; and it is probably to circumstances of this nature that we must ascribe the origin of the discontinuities which the discussion of Rumford's experiments has enabled us to state in the form of the law that the tension of the fluids of the powder depend on their density; and perhaps also the variations in the determination by different persons of the force of powder.

Experiment alone can solve this complex problem, whose complete solution will furnish the principal element of the dynamic theory of explosives.

CHAPTER III.

On the Work of Explosive Substances.

1. We have considered in the preceding chapter the pressure developed by the combustion of an explosive substance in a fixed and resisting envelope. We shall next study the effects produced by the expansion of the gas in a variable volume, as in a gun, from the displacement of the projectile.

At first, we shall consider only the more simple of these effects, in which, the explosion being *instantaneous*, we assume that the body is entirely gasified before the volume has appreciably altered. The case of a *progressive* combustion, in which the gases are produced during a change of volume, is much more complex, and will be made the subject of a special study.

2. *Work due to the expansion of an explosive body.*—Let unit of weight of the explosive deflagrate instantaneously in a capacity whose initial volume is v_0; call v the volume at any instant of the expansion; and let us find the work corresponding to the variation of volume $v - v_0$.

If we neglect the loss of heat due to the cooling of the walls of the envelope, the transformation is adiabatic; that is, unaccompanied by gain or loss of heat. Consequently, the work corresponding, $\mathfrak{C}$, is given by (21) of the first chapter; and we have

$$\mathfrak{C} = Ec(T_0 - T); \tag{53}$$

c being the specific heat of constant volume of the products of combustion, and T_0 and T the temperatures corresponding to the volumes v_0 and v.

$\mathfrak{C}$ may be expressed as a function of the volume when the ratio of the two specific heats of the gas remain sensibly the same during the expansion. Equation (20) shows that Tv^{n-1} is then constant.

We thus have $$Tv^{n-1} = T_0 v_0^{n-1},$$

and consequently $$T = T_0\left(\frac{v_0}{v}\right)^{n-1},$$

whence we derive the new value

$$\mathfrak{C} = EcT_0\left[1 - \left(\frac{v_0}{v}\right)^{n-1}\right]. \tag{54}$$

But according to equation (40), the product cT_0 is equal to the heat of combustion Q. We may therefore write

$$\mathfrak{C} = EQ\left[1 - \left(\frac{v_0}{v}\right)^{n-1}\right], \tag{55}$$

and the work due to the combustion of any quantity ω of the substance is, evidently,

$$(56) \qquad \mathfrak{C} = EQ\omega\left[1 - \left(\frac{v_0}{v}\right)^{n-1}\right].$$

3. *Maximum work or potential of an explosive substance.*—If v increases indefinitely, the limiting value of the work is, by (55),

$$(57) \qquad h = EQ.$$

Consequently, *the work due to the indefinite expansion of unit of weight of a burned explosive is equal to the product of the mechanical equivalent by the heat of combustion.*

This maximum work we shall call the *potential* of the explosive substance.

It is important to notice that the expression $h = EQ$ of the maximum work that unit of weight of an explosive can produce is independent of the phenomena of dissociation; and remains the same in the case where the specific heat of the products of combustion varies during the expansion, in consequence of sudden changes in the chemical state of these products. In fact, from the equation,

$$EcdT + pdv = 0,$$

which represents an infinitely small adiabatic transformation (Chapter I, No. 10), we derive, in all cases where the temperature varies from T_0 to absolute zero,

$$\mathfrak{C} = \int pdv = E\int_0^{T_0} cdT,$$

and the integral $\int_0^{T_0} cdT$ represents, in all cases, the total heat given out by the products in passing from zero to T_0; that is to say, the heat of combustion Q.

In equations (55) and (56) it is assumed, on the contrary, that the ratio n of the two specific heats remains sensibly constant during the expansion that is considered.

4. *Potentials of some explosive substances.*—The following table exhibits the values of the potentials of some powders and other explosives. These have been calculated by multiplying the experimental heats of combustion (Chapter II, No. 9) by 436. The products being divided by 1000, the figures of the table are tonnemeters.

Name of explosive.	Potential.
Sporting powder,	370
Cannon powder,	347
Fine-grained powder, called B,	337
Powder of commerce,	321
Ordinary blasting powder,	267
Chloride of nitrogen,	148
Nitro-glycerine,	778
Gun-cotton,	489
Picrate of potassium,	366
55 parts of picrate of potassium and 45 of saltpetre,	420
Equal parts of picrate and chlorate of potassium,	534

5. *Hypothesis of Bunsen and Schischkoff.*—In their chemical theory of the combustion of gunpowder, Bunsen and Schischkoff have calculated in a different way the maximum work of the powder with which they experimented. They made the calculation as though the solid residues found after the cooling remained solid throughout the phenomena and kept their initial temperature; thus evaluating only the work of the adiabatic expansion of the permanent gases.

In this hypothesis, formula (53) for the work is replaced by the following:

$$\mathfrak{C} = \varepsilon E c_1 (T_0 - T),$$

where ε is the weight and c_1 the specific heat of the *gaseous* products of the combustion of a kilogram of the substance.

But we have always $c T_0 = Q$, Q being the heat of combustion and c the specific heat of the *entirety* of the products.

We may then write

$$\mathfrak{C} = \frac{\varepsilon c_1}{c} E Q \left(1 - \frac{T}{T_0}\right),$$

and, in particular, if T tends towards zero, we have the limiting value,

$$h = \frac{\varepsilon c_1}{c} E Q.$$

According to this hypothesis, then, the value of the potential is a fraction of what we have found. For example, for sporting powder, the ratio $\frac{c_1}{c}$ differing little from unity, and ε being $\frac{1}{3}$, about, we find from the corresponding value of EQ, $h = 120$ tonne-meters, about.

This manner of calculating the work of explosive substances appears, however, hardly admissible. Bunsen and Schischkoff themselves admit that the volatilization of the solid residues at the temperature of

combustion, if not certain, is, at least, highly probable; and, if it be true, as these chemists incline to think, that the resulting vapors have a tension which may be neglected in comparison with those of the permanent gases, the heat which they give out in cooling to the mean temperature of the mixture is none the less transformed into work.

It is not reasonable that these products should keep the same temperature during the whole expansion; and if we admit, on the contrary, that, vaporized, or even solidified, they have at each instant the same temperature as the gas, we must adopt the value of the potential which we have already laid down.

In fact, in this second hypothesis the expansion of the gases ceases to be adiabatic, since they absorb the heat given out by the other products in cooling to the mean temperature of the mixture. If we call ε and $1-\varepsilon$ the relative proportions of the gaseous and non-gaseous products, and c_1 and c_2 the respective specific heats,

$$c = \varepsilon c_1 + (1-\varepsilon) c_2$$

represents the mean specific heat of the mixture.

In cooling from T_0, the initial temperature, to T, the temperature after expansion, the products give up a quantity of heat represented by $q = (1-\varepsilon)\, c_2\, (T_0 - T)$; and equation (10) applied to a weight ε of gas passing from T_0 to T, gives

$$(1-\varepsilon)\, c_2\, (T_0 - T) = \varepsilon c_1\, (T - T_0) + \frac{\mathfrak{C}}{E},$$

whence we derive

$$\mathfrak{C} = E\,[(1-\varepsilon)\, c_2 + \varepsilon c_1]\,[T_0 - T],$$

that is to say—

$$\mathfrak{C} = Ec\,(T_0 - T),$$

an expression identical with (53), and leading, like it, to the value of the potential, $h = EQ$.

6. *First approximation to initial velocities.*—Formula (56) gives a first approximate determination of the initial velocity of a projectile.

If we suppose that the combustion of the powder is instantaneous, and if we neglect the loss of heat to the walls of the gun, this formula will express the work done by the gas in terms of the energy of the projectile.

We have thus—

$$\frac{mV^2}{2} = h\omega\left[1 - \left(\frac{v_0}{v}\right)^{n-1}\right], \tag{58}$$

where

V is the initial velocity,

m the mass of the projectile,

ω the weight of the charge of powder,
h the potential of the powder,
v_0 the volume of the powder chamber,
v the total capacity of the bore,
n the mean value of the ratio of the two specific heats of the products of combustion.

For this last element we may adopt, following what has already been laid down (Chapter II, No. 17), the approximate value

$$1 = n + \frac{2\varepsilon}{5}, \tag{59}$$

in which ε is the weight of gas yielded by the combustion of a kilogram of the powder used.

From (58) we have

$$V = \left(\frac{2h\omega}{m}\right)^{\frac{1}{2}} \left[1 - \left(\frac{v_0}{v}\right)^{n-1}\right]^{\frac{1}{2}}, \tag{60}$$

as the expression for the initial velocity, if the combustion is instantaneous and no heat is lost.

We shall show how this formula may be modified to take account of the progressive burning of the grains and of the loss of the heat of the products of combustion to the walls of the gun.

PART II.

EFFECTS OF POWDER IN GUNS.

CHAPTER I.

EQUATION OF MOTION OF A PROJECTILE IN THE BORE.

1. In treating this problem we shall suppose that all the products of combustion are in the state of permanent gas.

In forming the equation, certain circumstances of secondary importance will be neglected. It will be assumed, in particular, that the observed effects are exempt, or corrected for, the influences of the vent and of windage, and that the influence of rotation and resistance to forcing the projectile into the grooves has been compensated for by a proper variation of the mass of the projectile.

We shall also neglect the cooling effect of the walls of the gun, but shall return to this in a subsequent chapter.

2. From the beginning of the inflammation of the charge, the gas is formed progressively, spreads in every direction, and displaces the projectile, carrying with it the part of the charge not yet burned.

At any given instant, the density of the gas varies at different points of its mass according to an unknown law; the temperature also varies, doubtless, as the parts of gas just formed are mixed with other parts which have been cooled by expansion: for this actual state we shall substitute one in which the density and temperature are the same throughout, and equal to the mean density and temperature.

The hypothesis of a mean temperature is very nearly the same as assuming that the gaseous products during each infinitely short period of time are instantly lowered to the temperature of the gas already formed.

3. Following this hypothesis, let, at any instant t, $y = F(t) =$ the weight of the products of combustion; and $T =$ their absolute temperature.

Consider the change due to an infinitely short period of time, dt.

During the time dt, the weight y is increased by dy; and this quantity dy, in falling from the temperature of combustion T_0 to the mean temperature of the products T, gives out a quantity dq of heat, which is equal to the product of dy by c (the specific heat of constant volume) by $T_0 - T$ (the difference of temperature). Thus

$$(1) \qquad dq = c(T_0 - T)\,dy.$$

In the same time, the quantity of gas already formed y, absorbs the heat dq, does the external work $d\mathfrak{C}$, and its temperature T varies dT.

Between the variations dq, $d\mathfrak{C}$, and dT, we have the thermodynamic relation,

$$(2) \qquad dq = cy.dT + \frac{d\mathfrak{C}}{E},$$

as will be apparent from (8) of Part I; recollecting that pdv is the element of external work, and that $\frac{R}{c' - c} = E$ (13).

Substituting in (2) the value of dq from (1), we have

$$\frac{d\mathfrak{C}}{E} = c(T_0 - T)\,dy - cy.dT = d[y(T_0 - T)];$$

consequently, integrating from the origin of inflammation,

$$(3) \qquad \frac{\mathfrak{C}}{E} = cy(T_0 - T).$$

4. We may transform this equation by means of the relation between the temperature of a gas and its volume and pressure.

Let $p =$ the pressure of the gas on unit surface,

$V =$ its volume; so that

$v = \frac{V}{y}$ is the volume of unit weight.

We have then

$$(4) \qquad pV = RyT,$$

R being a constant depending on the nature of the gas.

From (3) and (4) we have,

$$(5) \qquad cpV + \frac{R\mathfrak{C}}{E} = cRT_0y.$$

We observe the following:

1st. The specific heat of constant pressure being c', we have

$$E = \frac{R}{c' - c},$$

hence, putting as before $n = \frac{c'}{c}$, from (5)

$$\frac{R}{E} = c(n - 1). \tag{6}$$

2d. The product of RT_0 represents, as shown by (4), the value of p corresponding to $T = T_0$, $V = 1$, and $y = 1$. It is, therefore, *the pressure developed, in constant volume, by unit weight of powder exploding in unit volume.* We shall call this quantity the *force* of the powder.

Calling this f, and recollecting (6), (5) may be written

$$pV + (n - 1)\mathfrak{C} = fy. \tag{7}$$

Such is the relation which exists, at each instant of the expansion, between the weight, the pressure, and the external work.

5. To deduce from this the equation of motion, let

$m =$ the mass of the projectile;

$\omega =$ its transverse section, supposed equal to that of the bore;

$u =$ its displacement at any time t.

Neglecting the displacement of the gun during the motion of the projectile, the work $\mathfrak{C}$ will be given by the equation,

$$\mathfrak{C} = \tfrac{1}{2} m \left(\frac{du}{dt}\right)^2. \tag{8}$$

Also, the moving force being $p\omega$, we have

$$p\omega = m\frac{d^2u}{dt^2}. \tag{9}$$

The volume occupied by the gas V is composed of

1st. The initial volume V_0 existing around the charge before the displacement of the projectile;

2d. The volume of the interstices around the grains in the fraction of the charge which is lighted. Let $y_1 = F_1(t)$ be this volume;

3d. A volume equal to that of the powder which has burned, that is, to $\frac{y}{\delta}$, δ being the density of the powder;

4th. The cylindrical space ωu, equal to the displacement of the projectile.

We have then, $$V = V_0 + y_1 + \frac{y}{\delta} + \omega u,$$

or simply

$$V = \omega(u + z), \tag{10}$$

if we put, for shortness,

$$z = \frac{1}{\omega}\left(V_0 + y_1 + \frac{y}{\delta}\right). \tag{11}$$

We have from (9) and (10),

$$pV = m(u + z)\frac{d^2u}{dt^2}.$$

Substituting this in (7), and replacing $\mathfrak{C}$ by its value from (8), we have the following equation, which gives the motion of a projectile in a gun,

$$(u + z)\frac{d^2u}{dt^2} + \frac{n-1}{2}\left(\frac{du}{dt}\right)^2 = \frac{fy}{m}. \tag{12}$$

The problem is then reduced to finding the integral of this equation; it being evident that it and the first derivative $\frac{du}{dt}$ must vanish when $t = 0$.

6. If we consider the combustion instantaneous, the weight of powder burned y becomes equal to the weight of the charge ϖ, and the gas formed occupies immediately the whole of the *powder chamber.*

7. If then we call u_0 the *reduced length of the powder chamber*, that is to say, the height of an equivalent cylinder having for its base the section of the bore ω, we have $z = u_0$ in (10).

Consequently (12) becomes

$$(u + u_0)\frac{d^2u}{dt^2} + \frac{n-1}{2}\left(\frac{du}{dt}\right)^2 = \frac{f\varpi}{m}: \tag{13}$$

in this form it is directly integrable.

Let $v =$ the velocity of the projectile, then we have

$$(u + u_0)\,v\frac{dv}{du} + \frac{n-1}{2}v^2 = \frac{f\varpi}{m}, \tag{14}$$

or, separating the variables,

$$\frac{2vdv}{v^2 - \dfrac{2f\varpi}{(n-1)m}} + (n-1)\frac{du}{u + u_0} = 0,$$

and integrating,

$$\left[v^2 - \frac{2f\varpi}{(n-1)m}\right](u + u_0)^{n-1} = C,$$

where C is a constant which may be determined by the condition that when $v = 0$, $u = 0$; hence

$$C = -\frac{2f\varpi}{(n-1)m}u_0^{n-1},$$

therefore

$$(15) \qquad v^2 = \frac{2f\varpi}{(n-1)m}\left[1-\left(\frac{u_0}{u+u_0}\right)^{n-1}\right].$$

This formula is the same as (58) of Part I. It may be put in the same form by means of (49) of Part I.

8. To suppose that the combustion is instantaneous, is not however permissible. If it were so, the gases being suddenly formed in a volume very nearly equal to that of the powder, would produce enormous pressures which the gun could not withstand. It is only by the use of *progressive powder* that the high velocities and low pressures of recent times have been attained.

We must, therefore, in (12), consider y and z as functions of t. In this case, however, the integration by ordinary methods becomes impossible.

We can obtain, however, approximate values of the integral in two extreme cases when the displacement which it represents is very great or very small compared to the reduced length of the chamber.

These two cases are, moreover, very important. The first corresponds to the ordinary cases in practice, where the chamber is generally only a rather small fraction of the volume of the bore. The examination of the second case leads to some interesting results concerning the law of tension near the origin of motion, and consequently concerning the high pressure which it is generally believed is produced at that time. The first of these cases only will be treated here.

9. Before attempting the approximate solution of (12), we may remark that it depends upon the form of the two functions $F(t)$ and $F_1(t)$, which will vary according to the manner of combustion of the charge.

We shall resume first, adding some new considerations, the notions we now have concerning these functions.

CHAPTER II.

On the Form of the Function $y = F(t)$, representing the Combustion of the Charge.

10. The exact determination of the function $F(t)$ presents great difficulties. Its form depends at the same time on the physical properties of the powder, on the form and dimensions of the charge, on the position of the vent, etc.

Piobert was the first to give its form by formulas which he had obtained under the supposition that the portion of the charge not ignited retained at each instant the form which it had before the charge was ignited, and further, that the ignition was propagated spherically with a constant velocity around each of the points of the exterior surface successively reached by the flame.

We are able to clear the problem of these restrictions and to establish, following the track of Piobert, several very complete simple formulas, rigorously determining the function $F(t)$ by the aid of two new functions $\varphi(t)$ and $\psi(t)$, defined as follows:

11. We designate by ϖ the weight of the charge of powder, $\varphi(t)$ the fraction of this charge which is in ignition at any time t reckoned from the beginning of ignition, $\psi(t)$ the fraction of one of the grains (supposed equal) of the charge which is burned after a time t, counting from the instant when the exterior surface of this grain is reached by the flame.

Then let t be any given epoch of the combustion and x any previous time; after the time x the weight of the powder in ignition is $q = \varpi\varphi(x)$. If the time x increases by dx, q receives the increase $dq = \varpi\varphi'(x)dx$.

During the time $t - x$ which elapses between the time x and t, a portion of the element dq is burned, and this portion is equal to $dq.\psi(t-x) = \varpi\varphi'(x)\psi(t-x)dx$.

The total quantity of powder burned is obtained by integrating this expression between the limits 0 and t, and we have

$$F(t) = \varpi\int_0^t \varphi'(x)\,\psi(t-x)\,dx. \tag{16}$$

Before making hypotheses with regard to the functions φ and ψ, we shall deduce from this formula some general properties of the function F.

12. *The function $y = F(t)$ is discontinuous.* In fact, designate:

1st, by θ the time at which all the grains are ignited;

2d, by τ the duration of the combustion of a grain.

For values of x greater than θ we have always $\varphi(x) = 1$, and consequently $\varphi'(x) = 0$. The corresponding elements of the integral being also 0, it suffices to integrate between the limits 0 and θ. We have then for values of t greater than θ,

$$F(t) = \varpi\int_0^\theta \varphi'(x)\,\psi(t-x)\,dx. \tag{17}$$

If we suppose in the second place $t > \tau$, the value of $\psi(t-x)$ reduces to unity for those values of x such that $t-x > \tau$, that is to say, for such values of x as are less than $t-\tau$. It results then, for values of x between o and $t-\tau$, the element of the integral reduces to $\varphi'(x)dx$, so that we have:

$$F(t) = \varpi \int_0^{t-\tau} \varphi'(x)\,dx + \varpi \int_{t-\tau}^{t} \varphi'(x)\,\psi(t-x)\,dx,$$

that is to say,

$$(18) \qquad F(t) = \varpi\varphi(t-\tau) + \varpi \int_{t-\tau}^{t} \varphi'(x)\,\psi(t-x)\,dx.$$

From formulas (16), (17) and (18) it is easy to conclude that the function $F(t)$ is generally represented by three functions, which are substituted the one for the other during the total duration of combustion. We have in fact:

1st. If $\theta < \tau$,

$$(19) \quad \begin{cases} \text{from } t=0 \text{ to } t=\theta; & F(t) = \varpi \int_0^{t} \varphi'(x)\,\psi(t-x)\,dx \\ \text{from } t=\theta \text{ to } t=\tau; & F(t) = \varpi \int_0^{\theta} \varphi'(x)\,\psi(t-x)\,dx \\ \text{from } t=\tau \text{ to } t=\theta+\tau; & F(t) = \varpi \int_{t-\tau}^{\theta} \varphi'(x)\,\psi(t-x)\,dx \\ & \qquad + \varpi\varphi(t-\tau). \end{cases}$$

2d. If $\theta > \tau$,

$$(20) \quad \begin{cases} \text{from } t=0 \text{ to } t=\tau; & F(t) = \varpi \int_0^{t} \varphi'(x)\,\psi(t-x)\,dx \\ \text{from } t=\tau \text{ to } t=\theta; & F(t) = \varpi \int_{t-\tau}^{t} \varphi'(x)\,\psi(t-x)\,dx \\ & \qquad + \varpi\varphi(t-\tau) \\ \text{from } t=\theta \text{ to } t=\theta+\tau; & F(t) = \varpi \int_{t-\tau}^{\theta} \varphi'(x)\,\psi(t-x)\,dx \\ & \qquad + \varpi\varphi(t-\tau): \end{cases}$$

the discontinuities corresponding to the values θ and τ of the time.

13. For each of the values θ and τ the first derivatives of two functions which are substituted the one for the other have equal values. This remarkable property of the function $F(t)$ is established without difficulty by differentiating the expressions (19) and (20) with respect to t and substituting the particular values of θ and τ in the results obtained.

It follows then, that if we represent by a curve the general form of the function $F(t)$, it will be composed of three successive arcs having a common tangent at the points of discontinuity.

14. *The case in which the duration of ignition bears a very small ratio to the duration of combustion of a grain.*

When the charge is very small or when the interstices between grains offer an easy passage to the burning gases, it is conceivable that the necessary time for all the grains to be reached by the flame is very small, and may be neglected in comparison with the total period of the combustion of a grain.

We can then suppose that all the grains are ignited simultaneously, and it follows that the combustion of the whole charge would be represented by the same function as that of the combustion of each grain. We have then, very nearly,

$$F(t) = \varpi\psi(t). \tag{21}$$

15. *The case in which the duration of ignition is very great with respect to the duration of the combustion of a grain.*

We suppose that θ is very great with respect to τ, we then can only consider the value of $F(t)$ between the limits of τ and θ, that is to say, the second of the values (20), which for values of t notably greater than τ, reduces to the following:

$$F(t) = \varpi\varphi(t). \tag{22}$$

16. *General form of the function* $F(t)$.—The functions φ and ψ can in general be developed by McLaurin's Theorem, following the powers of t; it follows then, from (21) and (22), the function $F(t)$ is of the form

$$F(t) = \varpi(at + bt^2 + ct^3 + \ldots), \tag{23}$$

when the duration of ignition of the charge is very great or very small with respect to the duration of combustion of a grain.

When these two periods are comparable the combustion operates in three distinct phases; and it is easy to establish by the aid of formulas (19) and (20), that during the first phase, the function $F(t)$ may be reduced to the form,

$$F(t) = \varpi(at^2 + bt^3 + \ldots), \tag{24}$$

that is to say, it has its first term proportional to the square of the time, if each of the functions φ and ψ have, following formula (23), their first term proportional to this variable.

It may be added that the same formula (24) may represent with a certain approximation the second phase of the combustion, because of the common value which has been shown to be true of the first and second derivatives of the two functions at the common point of discontinuity (No. 13), which are substituted the one for the other at this point.

We observe, then, that we may, in this case, represent by a continuous formula of interpolation, the whole of the combustion of the charge.

Resuming, one can readily include this formula of interpolation, as well as formulas (22) and (24), in the general form,

$$F(t) = \varpi a t^{\varepsilon}(1 + \lambda t + \mu t^2 + \ldots), \tag{25}$$

ε being an exponent equal in these limited cases to 1 or to 2, but the value of which we can leave undetermined in the calculations, it being safe to determine it later by the comparison of results obtained in theory and those of practice, in order to represent in the best possible manner the effects produced.

17. *Some particular forms of the function which represents the combustion of the grain.*

We determine very easily the form of the function by supposing, with Piobert, that all the exterior parts of the surface of a grain are ignited at the same instant, and that the combustion is propagated with a constant velocity normal to the surfaces in ignition.

We here restate the formulas for certain cases which we are to examine in the course of these researches.*

1st. *Spherical grains.*—Denoting by r the radius of the grain, and by v the velocity of combustion, we have

$$\psi(t) = 1 - \left(1 - \frac{vt}{r}\right)^3,$$

or better, calling τ the duration of the combustion of a grain, and observing that $r = v\tau$:

$$\left\{\begin{aligned} \psi(t) &= 1 - \left(1 - \frac{t}{\tau}\right)^3 \\ \psi(t) &= \frac{3t}{\tau} - \frac{3t^2}{\tau^2} + \frac{t^3}{\tau^3} \end{aligned}\right. \tag{26}$$

* The hypothesis of the uniformity of the velocity of combustion is certainly not exact. Zero with the pressure (experiments of Bianchi), this velocity is a rapidly increasing function of the pressure of the medium in which the combustion takes place. It is conceivable, however, that we can give to it approximately a mean value, constant under certain conditions of the use of the powder, and may use this value in the application of formulas to guns when the circumstances of firing are but little different.

2d. *Cylindrical grains.*—Given h as the height of a grain and r the radius of its base, we find

$$\psi(t) = 1 - \left(1 - \frac{vt}{r}\right)^2 \left(1 - \frac{2vt}{h}\right)$$

$$(27) \quad \psi(t) = 2v\left(\frac{1}{r} + \frac{1}{h}\right)t - \frac{v^2}{r}\left(\frac{1}{r} + \frac{4}{h}\right)t^2 + \frac{2v^3}{hr^3}t^3$$

3d. *Pierced cylindrical grains.*—We suppose the grain to be a cylinder, radius of base r, pierced at its axis by a small concentric cylindrical canal of radius r', calling h the height, we have easily:

$$(28) \quad \begin{cases} \psi(t) = 1 - \left(1 - \frac{2vt}{h}\right)\left(1 - \frac{2vt}{r - r'}\right) \\ \psi(t) = 2v\left(\frac{1}{h} + \frac{1}{r - r'}\right)t - \frac{4v^2}{h(r - r')}t^2. \end{cases}$$

Formulas (26) can be applied to the normal conditions of practice; in fact, the grains, not sensibly spherical, approach nearly to a cubical form, but the formulas for spherical grains include those for a cubical form, and in general those of all grains of any polyhedral form that can be circumscribed by a sphere. With regard to formulas (27) and (28), they serve to study the effects produced by cylindrical grains, or pierced cylindrical grains (Russian prismatic powder) which have been used recently (1875) in guns of very large calibre.

18. *On the form of the function $\varphi(t)$ which represents the ignition of the charge.*—The function $\varphi(t)$ is an element whose determination offers great uncertainties. In order to find it, the hypothesis is generally made that the portion of the charge not in ignition retains at each instant the form which it had before the charge was ignited.

This hypothesis is perhaps true at the beginning of combustion, because the projectile has not been sensibly displaced, but it is probable that the charge is violently deformed by the pressure of the first gas produced, which acts unequally on the various points of its exterior surface. The grains which compose the charge are irregularly dispersed in the rapidly increasing space occupied by the products of combustion.

There is then foundation for the thought that the effects produced, particularly in long-bored guns, nearly approach those which are obtained if all the grains of the charge are ignited simultaneously.

It may, however, happen, particularly when the charge is very large and when the grains are small, that the flame communicated to

the charge is propagated gradually and slowly traverses the small interstices which separate the grains. These grains, on the other hand, burn with rapidity, and the rear of the charge, entirely burned before the flame is communicated to the whole charge, carries forward the projectile and the rest of the charge, which burns in the bore, or perhaps it does not burn until after the projectile has left the bore.

In order to evade these difficulties it is better to discard all hypotheses and to represent the law of combustion by formula (25), resorting to experiment, if necessary, to show how the coefficients ε, a, λ, μ . . . . depend upon the conditions of firing.

19. *On the form of the function $y_1 = F_1(t)$, which represents the volume of the interstices of the portion of the charge in ignition.*

The general equation (12) of the motion of the projectile, includes, besides $F(t)$, another function of the time, designated by y_1 in the expression for z, (11), and which represents at any epoch of the combustion, the volume of the interstices of that portion of the charge which is in ignition at that epoch.

This function can be at once obtained, since we know the function $\varphi(t)$ which expresses the fraction of the charge in ignition; hence, let

$d =$ the *gravimetric* density of the charge,

$\delta =$ the density of the grain,

$\varpi\varphi(t) =$ the weight of the ignited portion of the charge,

$\frac{\varpi\varphi(t)}{d}$ is the total volume, and

$\frac{\varpi\varphi(t)}{\delta}$ is the volume of the grains.

$$y_1 = \varpi\left(\frac{1}{d} - \frac{1}{\delta}\right)\varphi(t). \tag{29}$$

20. *On the form of the function z in the case of instantaneous ignition.*

Since the conditions of firing are such that all the grains are simultaneously ignited, the first gas produced expands instantly through the interstices of the grains, and occupies, at the beginning, a volume equal to that of the powder chamber diminished by that of the grains.

This volume should be equal to $V_0 + y_1$ from the value of z, (11), and is evidently

$$\omega u_0 - \frac{\varpi}{\delta}.$$

If we put, then, for brevity,

$$(30) \qquad z_0 = u_0 - \frac{\varpi}{\omega\delta},$$

we have in this particular case,

$$(31) \qquad z = z_0 + \frac{y}{\omega\delta}.$$

21. It is to be remembered, finally, that if we call Δ the *density of loading* or the ratio of the weight of the charge to the volume of the powder chamber, we may write

$$\Delta = \frac{\varpi}{\omega u_0},$$

a relation which permits us to put formula (30) in two forms,

$$(32) \qquad z_0 = u_0\left(1 - \frac{\Delta}{\delta}\right),$$

$$(33) \qquad z_0 = \frac{\varpi}{\omega}\left(\frac{1}{\Delta} - \frac{1}{\delta}\right).$$

These we shall frequently use in the course of our researches.

CHAPTER III.

Approximate Integration of the Equation of Motion (12).

22. This equation is the following,

$$(34) \qquad (u+z)\frac{d^2u}{dt^2} + \frac{n-1}{2}\left(\frac{du}{dt}\right)^2 = \frac{fy}{m}.$$

If we suppose that the duration of the inflammation is very small as compared with that of combustion, the function y is of the form,

$$(35) \qquad y = \varpi at\,(1 + \lambda t + \mu t^2 + \ldots),$$

ϖ being the weight of the charge, and a, λ, μ constants depending upon the form and physical properties of the grains.

It may be shown that the method of integration need be slightly changed only in the general case when y is of the form (25), the exponent ε not being unity. In this case the function z, as well as the expression

$$V = \omega(u+z),$$

representing the volume occupied by the gas at any time, reduces (No. 20) to the expression

$$(36) \qquad z = z_0 + \frac{y}{\omega\delta},$$

z_0 having the values (32) or (33).

23. The integration will be much simplified by putting $z = z_0$. This gives too small a value to the volume occupied by the gas, since it neglects the volume of the powder which has been burned. But the resulting error will not be great, because the quantity which is neglected is infinitely small at the origin of motion, and subsequently, as the projectile moves, becomes a very small fraction of the total volume.

This simplification, without which the integration would perhaps be impossible, has then the result of giving too large a value to the pressure, and consequently to the acceleration of the projectile.

Putting $z = z_0$ in (34), replacing y by its value in (35), and writing for shortness,

$$(37) \qquad \frac{n-1}{2} = \theta, \qquad \frac{f\varpi a}{m} = K,$$

it becomes,

$$(38) \qquad (u + z_0)\frac{d^2u}{dt^2} + \theta\left(\frac{du}{dt}\right)^2 = Kt(1 + \lambda t + \mu t^2 + \ldots).$$

This is the final equation which we have to integrate, having given the initial conditions, $u = 0$, and $\frac{du}{dt} = 0$.

24. *First approximation.*—It has already been remarked that this expression does not appear to be integrable by ordinary methods. In attempting to represent it by a series arranged according to powers of t, the series is found to become rapidly divergent.

We shall, however, obtain a sufficient approximation by the following method: put $z_0 = 0$ in (38), and call u_1 those of the integrals of the equation

$$(39) \qquad u\frac{d^2u}{dt^2} + \theta\left(\frac{du}{dt}\right)^2 = Kt(1 + \lambda t + \mu t^2 + \ldots),$$

which vanish with their first derivatives when $t = 0$.

The equation (39), corresponding to a ballistic problem in which the volume occupied by the gas is always too small by ωz_0, gives for any value of t, values $\frac{d^2u}{dt^2}$, and consequently $\frac{du}{dt}$ and u greater than those given by (38). Consequently $u_1, \frac{du_1}{dt}, \frac{d^2u_1}{dt^2}$, are superior limits of u, $\frac{du}{dt}$, and $\frac{d^2u}{dt^2}$.

25. It is easy to show that the difference between u and u_1 is always less than z_0. We have from (38),

$$u + z_0 = \frac{Kt(1 + \lambda t + \ldots) - \theta\left(\frac{du}{dt}\right)^2}{\frac{d^2u}{dt^2}}.$$

Putting in the second member of this equation $u = u_1$, we substitute for $\frac{du}{dt}$ and $\frac{d^2u}{dt^2}$ larger quantities, and consequently we diminish its value. Since, by (39), the second member becomes u_1, we have

$$u + z_0 > u_1,$$

and consequently, since $u_1 > u$,

$$u_1 > u > u_1 - z_0. \tag{40}$$

It results that the ratio $\frac{u}{u_1}$ approaches unity when, for increasing values of t, u becomes greater as compared with z_0. We may consequently take u_1 for the approximate expression of the displacement when this latter is considerably larger than z_0, which itself, by (32), is only a fraction of the length of the chamber.

This condition is satisfied in small arms when the projectile is near the muzzle. In great guns the capacity of the powder chamber cannot generally be considered as a very small fraction of the capacity of the bore. We shall see further on, how the solution may be modified so as to obtain a second approximation which appears to be sufficiently accurate for all purposes.

We shall first establish some important properties of the function u_1, defined by (39). It gives, it will be remembered, a first approximation to the solution in view.

26. *Integration of* (39) *by series.*—The integral u_1 of the auxiliary equation (39) may be expressed in a series of such rapid convergence that two or at most three terms suffice for purposes of application.

To satisfy this equation put

$$u_1 = At^\alpha(1 + bt + ct^2 + \ldots), \tag{41}$$

α, b, c, . . . being constants to be determined.

The equation becomes, after substitution,

$$[\alpha(\alpha - 1) + \alpha^2\theta]A^2t^{2\alpha-2}[1 + Pt + Qt^2 + \ldots] = Kt(1 + \lambda t + \mu t^2 + \ldots). \tag{42}$$

Writing, for shortness,

$$(43)\quad \begin{cases} P = \dfrac{2[\alpha + (\alpha + 1)\theta]}{\alpha - 1 + \alpha\theta}\, b, \\ Q = \dfrac{2[(\alpha^2 + \alpha + 1) + 2\alpha(\alpha + 2)\theta]c + [\alpha(\alpha + 1) + (\alpha + 1)^2\theta]b^2}{\alpha(\alpha - 1) + \alpha^2\theta}, \\ \dots\dots\dots\dots\dots\dots \end{cases}$$

we shall have an integral by taking

$$(44)\quad \begin{gathered} 2\alpha - 2 = 1, \quad [\alpha(\alpha - 1) + \alpha^2\theta]A^2 = K, \\ P = \lambda, \quad Q = \mu. \end{gathered}$$

From the first two of these we have

$$(45)\quad \alpha = \frac{3}{2}, \quad A = 2\left[\frac{K}{3(1 + 3\theta)}\right]^{\frac{1}{2}}.$$

The other equations will determine $b, c, \dots$ Replacing α by $\frac{3}{2}$, we have

$$(46)\quad \begin{cases} \dfrac{2(3 + 5\theta)}{1 + 3\theta} \cdot b = \lambda, \\ \dfrac{(38 + 42\theta)c + (15 + 25\theta)b^2}{3(1 + 3\theta)} = \mu, \\ \dots\dots\dots\dots\dots\dots \end{cases}$$

whence we have the values,

$$(47)\quad \begin{cases} b = \dfrac{1}{2} \cdot \dfrac{1 + 3\theta}{3 + 5\theta} \cdot \lambda, \\ c = \dfrac{1 + 3\theta}{38 + 42\theta} \cdot \left[3\mu - \dfrac{5}{4} \cdot \dfrac{1 + 3\theta}{3 + 5\theta}\lambda^2\right], \\ \dots\dots\dots\dots\dots\dots \end{cases}$$

Substituting the values of $\alpha, A, b, c, \dots$ in (45) and (47) in (41), that expression becomes an integral of (39). Also, this integral and its derivative vanish when $t = 0$; it satisfies therefore all the conditions imposed, and may serve in the evaluation of the integral we wish to determine.

27. *Expression of t as an explicit function of u_1.*—We derive from (41) the following expression for t,

$$(48)\quad t = \left(\frac{u_1}{A}\right)^{\frac{1}{\alpha}} + p\left(\frac{u_1}{A}\right)^{\frac{2}{\alpha}} + q\left(\frac{u_1}{A}\right)^{\frac{3}{\alpha}} + \dots$$

$p, q, \dots$ being coefficients which may be determined by substituting in (41) the value of t (48), and equating like powers of $\frac{u_1}{A}$. We thus find

$$
(49) \qquad \begin{cases} p = -\dfrac{1}{a} b \\[2ex] q = -\dfrac{1}{a} c + \dfrac{a+3}{2a^2} b^2, \\ \ldots\ldots\ldots\ldots \end{cases}
$$

and, replacing a by $\frac{3}{2}$,

$$
(50) \qquad \begin{cases} p = -\dfrac{2}{3} b \\[2ex] q = -\dfrac{2}{3} c + b^2 \\ \ldots\ldots\ldots \end{cases}
$$

28. *Expression of* $\frac{du_1}{dt}$ *as a function of* u_1.—Taking the derivative of u_1 with reference to t, we have

$$
(51) \quad \frac{du_1}{dt} = aAt^{a-1} + (a+1)\,bAt^{a} + (a+2)\,cAt^{a+1} + \ldots
$$

and, replacing t by its value in (48), we have

$$
(52) \quad \frac{du_1}{dt} = aA^{\frac{1}{a}} u_1^{\frac{a-1}{a}} + 2bu_1 + \left(3c - \frac{3a+1}{2a}\cdot b^2\right) A^{-\frac{1}{a}} u_1^{\frac{a+1}{a}} + \ldots
$$

which, writing $a = \frac{3}{2}$, becomes,

$$
(53) \quad \frac{du_1}{dt} = \frac{3}{2} A^{\frac{2}{3}} u_1^{\frac{1}{3}} + 2bu_1 + \left(3c - \frac{11}{6} b^2\right) A^{-\frac{2}{3}} u_1^{\frac{5}{3}} + \ldots
$$

where the values of A, b, c, . . . are to be taken from (45) and (47); K will be found in (37).

We have thus a first approximation for the velocity in terms of the space passed over.

29. *Approximate expression for the temperature.*—It will be of interest to find, in the degree of approximation adopted, the law by which the mean temperature of the products varies. It would always be T_0 if the products were formed without performing external work; it varies in a gun because of the expansion and the progressive burning of the powder.

The absolute temperature T at any time is determined by (4),

$$
T = \frac{pV}{Ry},
$$

and from (9) and (10),

$$
(54) \qquad T = \frac{m(u+z)\dfrac{d^2u}{dt^2}}{Ry}.
$$

Now, in the approximation adopted, we neglect z in comparison with u, and replace u by u_1. We have then

$$T = \frac{mu_1 \frac{d^2 u_1}{dt^2}}{Ry},$$

or, from the values of u_1 and y in (41) and (35), and replacing α by $\frac{3}{2}$,

(55) $$T = \frac{3}{4} \cdot \frac{A^2}{R\varpi a} \frac{1 + 6bt + \ldots}{1 + \lambda t + \ldots}.$$

We have also, from (45), $A^2 = \dfrac{4K}{3(1 + 3\theta)}$.

Finally, noting the value of K in (37), and that $f = RT_0$ (No. 4), this becomes

(56) $$T = \frac{T_0}{1 + 3\theta} \cdot \frac{1 + 6bt + \ldots}{1 + \lambda t + \ldots}.$$

The terms containing powers of t higher than the first have been neglected, for shortness. By (47), b, c, . . . may be expressed in terms of λ, μ, . . . , the coefficients of the function y, which represents the weight of powder burned. We may write then

$$T = \frac{T_0}{1 + 3\theta} \chi(t),$$

$\chi(t)$ being a function which depends exclusively upon the law which governs the manner of combustion of the charge. It is clear that (56) does not represent the thermic state at the origin. From the approximation adopted to establish this formula, we see that it represents a state towards which the real state tends as the displacement increases.

30. If the combustion of the charge were uniform, (35) would reduce to its first term; and we would have $\lambda = 0$, $\mu = 0$, . . . , $b = 0$, $c = 0$, . . . , and consequently

$$T = \frac{T_0}{1 + 3\theta}.$$

This, then, is the limiting temperature, towards which the real temperature would approach in this case. In all cases, from the moment when the combustion is complete, the temperature varies according to the known law of adiabatic transformations.

31. *Second approximation.*—We shall now see how we may, in guns in which the powder chamber is not a very small fraction of the bore, obtain a more exact formula for the muzzle velocity than that which results from (53).

We derive from (38)

$$\theta\left(\frac{du}{dt}\right)^2 = Kt(1+\lambda t+\ldots)-(u+z_0)\frac{d^2u}{dt^2}.$$

Replacing u by u_1 in the second member, we diminish its value; we have therefore,

$$\theta\left(\frac{du}{dt}\right)^2 > Kt(1+\lambda t+\ldots)-(u_1+z_0)\frac{d^2u_1}{dt^2},$$

that is, from (39) which u_1 satisfies,

$$\theta\left(\frac{du}{dt}\right)^2 > \theta\left(\frac{du_1}{dt}\right)^2 - z_0\frac{d^2u_1}{dt^2}.$$

Consequently, if we determine v by the expression

$$v^2 = \left(\frac{du_1}{dt}\right)^2 - \frac{z_0}{\theta}\frac{d^2u_1}{dt^2}$$

we shall get too small a value. Writing $\frac{du_1}{dt} = v_1$, we have

$$v^2 = v_1^2 - \frac{z_0}{\theta}\frac{dv_1}{dt},$$

and, supposing the second term small compared with the first, we have the approximate value

$$v = v_1 - \frac{z_0}{2\theta v_1}\frac{dv_1}{dt}.$$

We have also,

$$\frac{dv_1}{dt} = \frac{dv_1}{du_1}\cdot\frac{du_1}{dt} = \frac{dv_1}{du_1}v_1,$$

consequently

$$v = v_1 - \frac{z_0}{2\theta}\frac{dv_1}{du_1}.$$

Substituting for v_1 its value in (53), we have

$$v = \frac{3}{2}A^{\frac{2}{3}}u_1^{\frac{1}{3}}\left(1-\frac{1}{6\theta}\cdot\frac{z_0}{u_1}\right)+2b\left(u_1-\frac{z_0}{2\theta}\right)$$
$$+\left(3c-\frac{11}{6}b^2\right)A^{-\frac{2}{3}}u_1\left(1-\frac{5}{3\theta}\cdot\frac{z_0}{u_1}\right)+\ldots \tag{59}$$

This value of v is too small; we may make an approximate correction in replacing u_1 by $u+z_0$, which is a superior limit. This gives

$$v = \frac{3}{2}A^{\frac{2}{3}}(u+z_0)^{\frac{1}{3}}\left(1-\frac{1}{6\theta}\cdot\frac{z_0}{u+z_0}\right)$$
$$+2b\left(u+z_0-\frac{z_0}{2\theta}\right)+\ldots \tag{60}$$

In its applications, we shall only use two terms of this equation, and shall neglect z_0 in the second term, which is generally only a

small fraction of the first. The formula for initial velocity then becomes

$$v = \frac{3}{2} A^{\frac{2}{3}} (u + z_0)^{\frac{1}{3}} \left(1 - \frac{1}{6\theta} \cdot \frac{z_0}{u + z_0}\right) + 2bu,$$

or

(61) $$v = \frac{3}{2} A^{\frac{2}{3}} u^{\frac{1}{3}} \varepsilon_1 + 2bu,$$

by putting

(62) $$\varepsilon_1 = \left(1 + \frac{z_0}{u}\right)^{\frac{1}{3}} \left(1 - \frac{1}{6\theta} \cdot \frac{z_0}{u + z_0}\right).$$

We have also, developing in powers of $\left(\frac{z_0}{u}\right)$,

(63) $$\varepsilon_1 = 1 - \left(\frac{1}{6\theta} - \frac{1}{3}\right) \frac{z_0}{u} + \left(\frac{1}{6\theta} - \frac{1}{18\theta} - \frac{1}{9}\right) \left(\frac{z_0}{u}\right)^2 + \ldots$$

32. We might be led to neglect, in the above value of ε_1, the terms containing z_0^2 and those following, as has been done in substituting the approximate value (58) for the value of v in (57). But the value of ε_1 would then be too small in guns where the ratio $\frac{z_0}{u}$ has a large value.

We shall satisfy, however, experimental facts if we use (63) and the approximation of (58). It appears that the agreement of theory and practice requires that, in place of (57) where the value of v is too small, we should use (58), which is greater than the exact square root.

33. *Formulæ of initial velocities.*—It only remains, to obtain our final formula, to substitute in (61), for A and b, their values, (45) and (47). Putting then,

(64) $$P = \left(\frac{9}{2 + 6\theta}\right)^{\frac{1}{3}}, \qquad Q = \frac{1 + 3\theta}{3 + 5\theta},$$

it becomes

(65) $$v = P \left(\frac{fa\varpi u}{m}\right)^{\frac{1}{3}} \varepsilon_1 + Q\lambda\mu;$$

where

f is the force of the powder,
ϖ the weight of the charge,
m the mass of the projectile,
u the space passed over by the projectile,
a, λ, are defined by the relation, $y = \varpi at(1 + \lambda t + \ldots)$, which represents the weight of powder burned after the time t.
ε_1 is given by (63),
z_0 is given by (32),

u_0 being the reduced length of the chamber,
Δ the density of loading,
δ the density of the grains,
P and Q are given by (64), and
$\theta = \frac{n-1}{2}$, n being the ratio of the two specific heats of the products of combustion.

34. *Influence of the mode of combustion.*—For each particular mode of combustion there is a corresponding form of (35), and consequently system of values of a, λ, . . . , which we have only to substitute in (65) to derive the theoretical results. We shall return to this subject, only examining now the case in which the grain is a sphere, or a polyhedron in which a sphere may be inscribed.

35. *Case of spherical grains.*—When the grain is a sphere, or a polyhedron which may be inscribed in a sphere, the combustion is represented by the formula

$$y = \frac{3\varpi t}{\tau}\left(1 - \frac{t}{\tau} + \frac{t^2}{3\tau^2}\right),$$

τ being the time of burning of a grain. We have consequently

$$(66) \qquad a = \frac{\tau}{3}, \quad \lambda = -\frac{1}{\tau}, \quad \mu = \frac{1}{3\tau^2};$$

and the various formulæ deduced in this chapter are reduced to the following:

1st. Coefficients b, c, . . . of u_1. The coefficients (47) of the series (41) become

$$(67) \qquad \begin{cases} b = -\frac{1}{2}\,\frac{1+3\theta}{3+5\theta}\cdot\frac{1}{\tau}, \\ c = \frac{1}{8}\cdot\frac{1+3\theta}{19+21\theta}\cdot\frac{7+5\theta}{3+5\theta}\cdot\frac{1}{\tau^2}. \end{cases}$$

These values are also necessary to calculate the coefficients of the series (50) and (53).

2d. *Formula of velocity.*—In this case, (65) becomes

$$v = 3^{\frac{1}{3}}P\left(\frac{f\varpi u}{m\tau}\right)^{\frac{1}{3}}\varepsilon_1 - Q\,\frac{u}{\tau}:$$

it is this form that we shall frequently apply in our researches.

But before discussing the results which we have obtained, and examining how far they are in accord with experimental facts, it is necessary to correct them for the cooling effect of the walls of the gun. The next chapter will be devoted to this point.

CHAPTER IV.

On the Effect of the Cooling of the Powder Gases by the Interior Wall of the Gun.

36. Hitherto, works on interior ballistics have not taken into account, to our knowledge, the effects of the cooling of the powder gases by the walls of the bore (1875). This cooling cannot be neglected; in fact, M. de Saint Robert shows experimentally, that by firing a gun the heat absorbed by the piece is a very notable fraction, a fourth for example, of the heat developed by the combustion of the charge.

It is then inexact to suppose that the total heat of combustion is transformed into work, and we shall proceed to show how we must, in consequence, modify the general equation for the movement of the projectile which we have established in the first chapter.

37. The fundamental relation of this analysis is equation (2), which is applied, during an infinitely small period of the expansion, to the thermodynamic transformation of the gases already formed. It expresses that the heat dq absorbed by these gases is equivalent to the alteration of their sensible heat, increased by the exterior work accomplished. When there is no heat lost the quantity dq is equal to the heat set free by the gaseous products during the infinitely small period dt of the transformation. It is then given by formula (1).

But if the walls of the bore absorb heat, it becomes necessary to deduce from (1) the quantity absorbed.

This quantity may be represented by $h\sigma dt$, σ being the enveloping surface of the volume occupied by the gas, and h the velocity of flowing of the heat for a unit of surface of the walls of the bore. The following value then follows:

$$dq = c(T_0 - T)dy - h\sigma dt, \tag{69}$$

which should be substituted for formula (1), and equation (2) then becomes

$$c(T_0 - T)\,dy - h\sigma dt = cy\,.\,dT + \frac{d\mathfrak{C}}{E}, \tag{70}$$

and integrating, since $t = 0$, we obtain the equation:

$$\frac{\mathfrak{C}}{E} = cy\,(T_0 - T) - \int_0^t h\sigma dt, \tag{71}$$

which takes the place of equation (3).

38. Introducing in (71) the pressure p and the volume V of the gas, we obtain the new equation:

$$pV + (n-1)\mathfrak{C} = fy - \frac{R}{c}\int_0^t h\sigma dt, \tag{72}$$

which corresponds to equation (7) of the first chapter.

We now show how the equation of the movement of the projectile is deduced.

The surface σ is the total surface of a cylinder having for a height the distance $u + u_0$ of the projectile from the bottom of the bore.

The surfaces of the two bases of this cylinder may be neglected, especially in the case of very long guns, in which the cooling of the gas has most influence; calling $2r$ the diameter of bore or the calibre of the gun, we have:

$$\sigma = 2\pi r(u + u_0),$$

or more simply

$$\sigma = 2\pi ru,$$

in cases in which the capacity of the bore is great with respect to that of the chamber.

The coefficient h is a function of the excess of the temperature of the gases over that of the wall of the bore. It varies also with the movement of the projectile, but we can substitute for it a constant approximate mean value, consequently equation (72) should be:

$$pv + (n-1)\mathfrak{C} = fy - \frac{2\pi rRh}{c}\int_0^t udt,$$

and it suffices to operate as in No. 5 to obtain the equation of the movement of the projectile.

39. By putting as heretofore $\frac{n-1}{2} = \theta$, and observing that $\frac{R}{c} = \frac{f}{q}$, q being heat of combustion of the powder; in fact, calling T_0 and q the temperature and the heat of combustion of the powder, and f the force of the powder, we have $f = RT_0$ and $q = cT_0$, so that $\frac{R}{c} = \frac{f}{q}$.

$$(u+z)\frac{d^2u}{dt^2} + \theta\left(\frac{du}{dt}\right)^2 = \frac{fy}{m} - \frac{2\pi rhf}{qm}\int_0^t udt. \tag{73}$$

In order to integrate this equation (73) we will neglect z, following the method of approximation of No. 23 we will obtain also, corrected by taking account of the cooling, the auxiliary integral designated by

u_1, and we will afterwards deduce by the formulas of No. 30 the definite integral of the problem.

The equation (73) contains the unknown function u under the integral sign. In order to evade this difficulty, it would suffice to differentiate with respect to t, which would give a differential equation of the third order; but it is more simple to operate by successive approximation and to integrate (73) after having replaced u under the integral sign by the value u_1, which may be integrated because we neglect the additional term.

We have then to integrate the equation

$$(74) \qquad u\frac{d^2u}{dt^2}+\theta\left(\frac{du}{dt}\right)^2=\frac{fy}{m}-\frac{2\pi rhf}{qm}\int_0^t u_1\,dt$$

in which the second term of the second member is still an unknown function.

40. In order to find the new integral we put

$$u=u_1+u_2,\quad \frac{d^2u}{dt^2}=\frac{d^2u_1}{dt^2}+\frac{d^2u_2}{dt^2}.$$

Substituting and reducing,

$$u_1\left(\frac{d^2u_1}{dt^2}+\frac{d^2u_2}{dt^2}\right)+u_2\left(\frac{d^2u_1}{dt^2}+\frac{d^2u_2}{dt^2}\right)+\theta\left(\frac{du_1}{dt}\right)^2+2\theta\frac{du_1}{dt}\cdot\frac{du_2}{dt}$$
$$+\theta\left(\frac{du_2}{dt}\right)^2=\frac{fy}{m}-\frac{2\pi rhf}{qm}\int_0^t u_1\,dt.$$

Neglecting the square of $\frac{du_2}{dt}$ and the product of u_2 and $\frac{d^2u_2}{dt^2}$, and recollecting the condition

$$u_1\frac{d^2u}{dt^2}+\theta\left(\frac{du_1}{dt}\right)^2=\frac{fy}{m},$$

we obtain the equation

$$(75) \qquad u_1\frac{d^2u_2}{dt^2}+2\theta\frac{du_1}{dt}\cdot\frac{du_2}{dt}+\frac{d^2u_1}{dt^2}u_2=-\frac{2\pi rhf}{qm}\int_0^t u_1\,dt,$$

which is linear with respect to u_2 and its derivatives.

This equation is easily integrated when we limit the value of u_1 to the first term of its development, (41). We have then

$$(76) \qquad u_1=At^{\frac{3}{2}},$$

A having the value (45), and equation (75) becomes

$$(77) \qquad t^2\frac{d^2u_2}{dt^2}+3\theta t\frac{du_2}{dt}+\frac{3}{4}u_2=-\frac{2}{5}\cdot\frac{2\pi rhf}{qm}t^3.$$

We obtain an integral which vanishes with its derivative, for $t=0$, by putting

$$(78) \qquad u_2 = -B.\frac{2\pi rhf}{qm}t^3,$$

B being determined by the condition:

$$B\left(6+9\theta+\frac{3}{4}\right)=\frac{2}{5},$$

whence

$$(79) \qquad B=\frac{8}{45}\cdot\frac{1}{3+4\theta}.$$

Consequently the integral of equation (74) is:

$$(80) \qquad u=u_1-B.\frac{2\pi rhf}{qm}t^3.$$

This is the function which must be substituted for u_1 in formula (57) in order to obtain the velocity of the projectile.

41. Also, in formula (58) we should add to v_1 the corrective term:

$$v_2=-3B.\frac{2\pi rhf}{qm}t^2,$$

which perhaps can be better expressed as a function of the space passed over, as in the case of v_1. We have from (76), $t=\left(\frac{u_1}{A}\right)^{\frac{2}{3}}$ and it follows that

$$v_2=-3B.\frac{2\pi rhf}{qm}\left(\frac{u_1}{A}\right)^{\frac{2}{3}}.$$

Replacing A by its value (45) and recollecting the value (37) of K, we have

$$v_2=-R\frac{2\pi rhf}{qm}\left(\frac{m}{f\varpi a}\right)^{\frac{2}{3}}.u_1^{\frac{4}{3}},$$

by putting for brevity

$$(81) \qquad R=\frac{24}{45}\left(\frac{3}{4}\right)^{\frac{2}{3}}\frac{(1+3\theta)}{3+4\theta}.$$

Finally, by replacing u_1 by the quantity u, the space passed over, which differs from u_1 by a quantity less than z_0, we have:

$$v_2=-R.\frac{2\pi rhf}{qm}\left(\frac{m}{f\varpi a}\right)^{\frac{2}{3}}u^{\frac{4}{3}}.$$

42. It follows, from what precedes, that formula (65) for velocities should be replaced by the formula:

$$(82) \qquad v=P\left(\frac{fa\varpi u}{m}\right)^{\frac{1}{3}}\varepsilon_1+Q\lambda u-R.\frac{2\pi rhf}{qm}\left(\frac{m}{f\varpi a}\right)^{\frac{2}{3}}u^{\frac{4}{3}}.$$

We can then combine the first and third terms after having multiplied the latter by ε_1 which alters its value very little, and which is

generally of little importance compared to that of the first term. We have thus:

$$P\left(\frac{fa\varpi u}{m}\right)^{\frac{1}{3}}\left(1-\frac{R}{P}\,\frac{2\pi rhu}{qa\varpi}\right)\varepsilon_1.$$

If then we put:

(83) $$\alpha=\frac{R}{P}=\frac{12}{45}\cdot\frac{1+3\theta}{3+4\theta},$$

(84) $$\varepsilon_2=1-\frac{\alpha h}{qa}\cdot\frac{2\pi ru}{\varpi},$$

we have definitely:

(85) $$v=P\left(\frac{fa\varpi u}{m}\right)^{\frac{1}{3}}\varepsilon_1\varepsilon_2+Q\lambda u.$$

43. The value (84) of the correction ε_2 relating to the cooling shows that it decreases for the same powder, characterized by the given values of c, f, a, according as the quantity $\frac{2\pi ru}{\varpi}$ increases. The effect of the cooling is, consequently, greatest when the weight of the charge bears a small ratio to the interior surface of the bore, a result not difficult of proof. This effect is also modified by the law of the combustion of the charge. We suppose, for example, that the grains are nearly spherical in form. The coefficient a is then equal to $\frac{3}{\tau}$, τ being the total period of combustion, and we have

(86) $$\varepsilon_2=1-\frac{\alpha h}{3q}\cdot\frac{2\pi ru\tau}{\varpi}.$$

It follows, then, other conditions being equal, the effect of cooling is the less according as the combustion of the powder is the more rapid.

44. Formula (86) includes the specific coefficient h which represents the velocity with which the absorption of heat is effected for a unit of surface of the bore. We have no experimental data at this time (1875) which gives the value of this coefficient in the extreme conditions of temperature realized in the bore of a gun. We will attempt at the time of numerical application of the formula to deduce its value from the discussion of observed velocities.

We will confine ourselves, at this time, to the observation that its value probably varies in the same sense as the calorific conductibility of the metal in the gun, and it is fair to suppose, for example, that it is greater for bronze than for iron or steel.

Formula (85) constitutes the definite result of these researches. We will perhaps examine in subsequent chapters how it may be applied to some of the more important cases of practice.

CHAPTER V.

Applications and Numerical Verifications.

45. We shall show in this chapter the methods which, it appears, will lead most exactly to the verification of the formula for velocities which has been obtained.

Resuming this formula, referring to Nos. 32 and 40 for the meaning of the letters which it contains,

$$v = P\left(\frac{fa\varpi u}{m}\right)^{\frac{1}{3}}\varepsilon_1\varepsilon_2 + Q\lambda u, \tag{87}$$

ε_1 and ε_2 being determined by the relations

$$\varepsilon_1 = 1 - \left(\frac{1}{6\theta} - \frac{1}{3}\right)\frac{z_0}{u} + \left(\frac{1}{6\theta} - \frac{1}{18\theta} - \frac{1}{9}\right)\left(\frac{z_0}{u}\right)^2 + \ldots \tag{88}$$

$$\varepsilon_2 = 1 - \frac{ah}{qa}\,\frac{2\pi ru}{\varpi}. \tag{89}$$

46. This system of formulæ depends, firstly, upon four characteristic elements of the powder used; namely, f, a, λ, θ. The first is the force of the powder, a and λ depend upon the mode of combustion of the charge, and θ is equal $\frac{n-1}{2}$; n being the ratio of the two specific heats of the products of combustion.

Secondly, the corrective coefficient ε_2 contains a coefficient h whose value *a priori* is unknown. We have then in all five unknown constants.

47. *Determination of θ.*—We may fix upon a value of θ which, within the narrow limits of change as to proportions and physical properties to be found in ordinary powders, will not be far from the truth.

We shall use for this the formula

$$n - 1 = \frac{2}{5}\varepsilon \tag{90}$$

(see Part I, Chapter II, No. 17). This formula gives n for any powder, when the weight of permanent gas of a kilogram of it (ε) has been determined by experiment.

We have made this determination for the various powders used in France; and it results from our determinations* that the values of

* Sur la chaleur de combustion des matières explosives, par MM. Roux et Sarrau (*Comptes-rendus de l'Academie des Sciences*, 14 juillet, 1873).

ε are respectively 412 and 414, say 413 as a mean value, for cannon powder, and small arm powder called B; that is to say, for two types which will probably include all war powders.

To this value of ε corresponds the value

$$n-1=.4\times .413=.1652,$$

and consequently,

$$\theta=\frac{n-1}{2}=.0826, \text{ or about } \frac{1}{12}\cdot$$

Such would be *a priori*, and independently of any ballistic results, the value we would give θ. But it has been found that the formulæ represent observed facts better by changing this value slightly, and taking

(91) $$\theta=\frac{1}{11}\cdot$$

We shall use this value in all the calculations which follow, and we find from it the value of ε_1 in the form,

(92) $$\varepsilon_1=1-\frac{3}{2}\frac{z_0}{u}+\frac{10}{9}\left(\frac{z_0}{u}\right)^2.$$

Consequently, the numerical values of P and Q, which depend upon θ, are found to be from (64),

(93) $$P=1.5234, \qquad Q=.3684.$$

48. This determination, whose exactness will be further confirmed in the sequel, being made, we shall show how the formula may be tested by means of initial velocities taken in varying conditions, but with *the same powder.*

Putting then,

(94) $$P(fa)^{\frac{1}{3}}=A,\ Q\lambda=-B,\ \frac{\pi ah}{qa}=\gamma,$$

$$\frac{z_0}{u}=\frac{u_0}{u}\left(1-\frac{\Delta}{\delta}\right)=x,$$

the formula we wish to verify is the following,

$$v=A\left(\frac{\varpi u}{m}\right)^{\frac{1}{3}}\varepsilon_1\varepsilon_2-Bu,$$

ε_1 and ε_2 having the values

(96) $$\begin{cases}\varepsilon_1=1-\dfrac{3}{2}x+\dfrac{10}{9}x^2,\\[2mm] \varepsilon_2=1-\gamma.\dfrac{2ru}{\varpi},\end{cases}$$

and we should be able, if the formula is exact, to determine a system of values for A, B, and γ such that they will give correct velocities

when we vary ϖ, u, m, . . ., upon which they depend, through large limits.

49. *Experiments which have been used in the verification of the formulæ.*—We have used the velocities given by the naval artillery commission, in the numerous series of experiments, with various conditions of loading, carried out by them at Gavre with guns of the model of 1870.

The total number of measured results which have been used in the determination of the coefficients is 24; they were all taken from the official publication in the *Memorial*, and are cited in the recapitulative table which follows.

50. *Description of the powder used.*—In all these experiments, Wetteren powder, of grains of 13 to 16 millimeters, was used. The proportions are the standard ones for war powder:

Saltpetre, 75; sulphur, 12.5; charcoal, 12.5.

Process of fabrication, *tonnes et meules;* number of grains to the kilogram, about 350. Density of grain, about 1.800.

The obligation which we have been under, of using samples of powder from various sources not having absolutely the same ballistic value, has necessarily caused some variations in the results.

Name of Gun.	(1) $2r$ Met.	(2) u Met.	(3) u_0 Met.	(4) p Kil.	(5) ϖ Kil.	(6) Δ	(7) v Met.
24 cent., model 1870, No. 24,	0.242	3.445	.763	144.	12.	0.342	253.3
					16.	0.456	306.6
					20.	0.570	350.2
					24.	0.684	393.2
					28.	0.798	432.0
24 cent., model 1870, No. 24,	0.242	3.445	.763	120.	12.	0.342	273.0
					16.	0.456	332.3
					20.	0.570	379.5
					24.	0.684	427.2
					28.	0.798	467.4
24 cent., model 1870, No. 24,	0.242	3.445	.763	96.	12.	0.342	300.1
					16.	0.456	363.0
					20.	0.570	420.6
					24.	0.684	469.2
					28.	0.798	512.5
14 cent., model 1870, No. 1,	0.140	2.761	0.205	18.65	2.0	0.637	322.0
					2.5	0.797	372.9
					3.0	0.956	419.6

Name of Gun.	(1) $2r$ Met.	(2) u Met.	(3) u_0 Met.	(4) p Kil.	(5) ϖ Kil.	(6) Δ	(7) v Met.
14 cent., model 1870, No. 4,	0.140	2.731	0.239	18.65	2.5	0.684	362.0
					3.0	0.820	404.6
					3.5	0.957	444.0
14 cent., model 1870, No. 2,	0.140	2.697	0.273	18.65	3.0	0.719	391.9
					3.5	0.838	431.2
					4.0	0.958	472.0

51. Legend of the table:

$2r$ is diameter of the bore;

u initial distance of the base of the projectile from the muzzle;

u_0 reduced length of the powder chamber, or length of a cylinder of equal volume having the right section of the bore as base;

p the weight of the projectile;

ϖ the weight of the charge;

Δ the density of loading, or ratio of the weight in kilograms of the charge to the volume in cubic decimeters of the charge;

v the initial velocity.

52. *Order followed in the determination of the constants.*—We shall determine the constants in the following order:

1st. B from observed velocities in the 24 cent. gun with different weights of projectiles.

2d. The coefficient of cooling γ from the nine velocities of the three guns of 14 cent.

3d. A from all the measured velocities.

53. *Determination of B.*—If we suppose that the mass of the projectile m is the only variable, the velocity is a function of it of the form

$$v = ax - b,$$

putting $\frac{1}{m^{\frac{1}{3}}} = x$. To determine b we must have then two corresponding values of v and m. From the two equations,

$$v_1 = ax_1 - b,$$
$$v_2 = ax_2 - b,$$

we have

$$a = \frac{v_1 - v_2}{x_1 - x_2},$$

and b may then be found from either of the preceding equations.

But the use of two observations only would not give close accuracy, for the variations of the weight of the projectile are small. It results, therefore, that the denominator of a is generally very small, which in-

creases an error in the numerator. It therefore becomes necessary to use a larger number of observations. We have proceeded as follows:

For the same charge of powder, and consequently for the same value of a, let

$$v_1, v_2, v_3,$$

be three velocities corresponding to three values of the mass of the projectile. Let the corresponding values of $\left(\frac{1}{m}\right)^{\frac{1}{3}}$ be x_1, x_2, x_3. We have then the equations,

$$(1) \quad v_1 = ax_1 - b,$$
$$(2) \quad v_2 = ax_2 - b,$$
$$(3) \quad v_3 = ax_3 - b,$$

From (1) and (2), and (2) and (3), we find two approximate values $a_{1.2}$ and $a_{2.3}$ of a; and we adopt the mean value

$$a = \frac{a_{1.2} + a_{2.3}}{2},$$

and from this find for b the three nearly identical values,

$$b_1 = ax_1 - v_1,$$
$$b_2 = ax_2 - v_2,$$
$$b_3 = ax_3 - v_3,$$

and take the mean of these. Operating in this manner with the velocities of the gun of 24 cent. with the same charge of powder, the following table of corresponding values of ϖ, a, b, is formed:

ϖ Kil.	a	b
28	1.365	125.4
24	1.291	133.9
20	1.166	123.8

The mean of the values of b is 127.7. Consequently, since $b = Bu$, and the value of u for the 24 cent. gun is 3.445, we have

$$(97) \qquad B = 37.07$$

54. *Determination of* γ.—The determination of B being made by the 24 cent. gun, which alone was fired with sufficient variation in the weight of the projectile; γ was calculated from the measured velocities with the 14 cent. gun, where the influence of the cooling was relatively greater.

To this end, values were calculated for the three guns.

1st. For Bu, which were respectively,

No. 1,	102.3
No. 4,	101.2
No. 2,	100.0

2d. The quantities W, obtained by adding the measured velocities to the corresponding values of Bu. These will be found in the following table:

ϖ Kil.	No. 1.	No. 4.	No. 2.
2.0	424.3		
2.5	475.2	463.2	
3.0	521.9	505.8	491.9
3.5		545.2	531.2
4.			572.0

3d. The values of $\frac{W}{\varepsilon_1}\left(\frac{m}{\varpi u}\right)^{\frac{1}{3}}$, which represent, by formula (95), the product of the constant A by the corrective coefficient ε_2. The following gives the results:

ϖ Kil.	No. 1.	No. 4.	No. 2.
2.0	319.7		
2.5	329.4	328.2	
3.0	336.8	334.0	332.6
3.5		338.5	337.7
4.0			344.3

The last table gives rise to an important remark. The figures on the same horizontal line are very nearly equal; in the one above, however, this is not the case, in consequence of the fact that, though the charge was the same, the values of the length of the charge and the density of loading were different.

It results from this that the factor ε_1, which takes account of these variations, represents exactly the influence which they have upon the velocity.

The differences in the same vertical column may therefore be supposed due to the cooling, whose effect would therefore be considerable in the gun of 14 cent. We see, also, that these differences are less with large charges, as should be the case: in fact, if we suppose that the figures of the table may be represented by the product $A\varepsilon_2$, A being a constant, and ε_2 a function of the form

$$\varepsilon_2 = 1 - \gamma \frac{2ru}{\varpi},$$

we have found that by taking

$$\gamma = 0.65,$$

the quotients of the figures of the table by the corresponding values of ε_2 are sensibly constant. This results from an examination of the following table, which contains the nine quotients giving as many approximate values of A:

ϖ Kil.	No. 1.	No. 4.	No. 2.
2.0	365.7		
2.5	366.1	364.5	
3.0	367.5	364.1	362.2
3.5		364.3	363.2
4.0			366.8
Means	366.4	364.3	364.1

55. *Determination of A.*—The three values of A determined from the velocities of the gun of 14 cent. agree very closely. It is important to see whether we obtain an identical value, or a very nearly equal one, by applying the same operations to the 15 velocities taken with the 24 cent. gun.

Consequently, the value of Bu, about 127.7, has been added to these, and the results W multiplied by $\frac{1}{\varepsilon_1 \varepsilon_2}\left(\frac{m}{\varpi u}\right)^{\frac{1}{3}}$; using, for the calculation of ε_2, the coefficient $\gamma = 0.65$, already found.

These products, which give corresponding values of A, are entered in the following table:

Weight of Charge ϖ; Kil.	Projectile. 144 Kil.	120 Kil.	96 Kil.
12	368.0	364.3	367.7
16	369.3	368.1	364.5
20	367.1	366.7	368.0
24	367.3	368.2	367.7
28	366.0	366.3	365.8
Means	367.5	366.7	366.7

The general mean, 367.0, differs very little from the values obtained with the 14 cent. gun.

For A, we have then a series of four values:

24 cent. gun, No. 24,	. . . . .	367.0
14 " " " 1,	. . . . .	366.4
14 " " " 4,	. . . . .	364.4
14 " " " 2,	. . . . .	364.1

whose mean is

(98) $$A = 365.5$$

56. *Resumé and formula for the Wetteren powder* (*grains of* 13 *to* 16 *mill.*).—We have then, for the powder used, the following coefficients:

$$A = 365.5$$
$$B = 37.07$$
$$\gamma = 0.65$$

whence the final formula,

(99) $$V = 365.5\left(\frac{\varpi u}{m}\right)^{\frac{1}{3}}\varepsilon_1\varepsilon_2 - 37.07u.$$

and

(100) $$\begin{cases} \varepsilon_1 = 1 - \frac{3}{2}x + \frac{10}{9}x^2, \\ x = \frac{u_0}{u}\left(1 - \frac{\Delta}{1.8}\right), \\ \varepsilon_2 = 1 - 0.65\frac{2ru}{\varpi}. \end{cases}$$

In the following table will be found a number of velocities calculated by this formula, together with the observed velocities. The table comprises, besides the 25 velocities which were used in the determination of the constants, the calculated and measured velocities in 35 other cases; namely,

1st. 18 with the gun of 14 cent. of various lengths, and various charges and projectiles;

2d. 7 of the 19 cent. gun with various charges and projectiles;

3d. 5 with the 24 cent. gun (No. 24) with cylindrical projectile of 144 kilos;

4th. 5 with the steel 24 cent. gun.

The observed velocities were all taken from the *Memorial.* There are in all 16 different conditions of fire, and the mean error of the calculated velocities is 2.8 meters.

57. Table giving calculated and corresponding measured velocities:

Name of Gun.	(1) $2r$ Meters.	(2) u Meters.	(3) u_0 Meters.	(4) p Kilos.	(5) ϖ Kilos.	(6) Δ	(7) Velocities — Measured. Meters.	Velocities — Calculated Meters.	Differences.
14 cent. model 1870, No. 1.	0.140	2.761	0.205	18.65	2.0	0.637	322.0	322.0	0
					2.5	0.797	372.	372.9	0
					3.0	0.956	419.6	417.0	+ 2.6
14 cent. model 1870, No. 4.	0.140	2.731	0.239	18.65	2.5	0.684	362.0	363.5	— 1.5
					3.0	0.820	404.6	406.8	— 2.2
					3.5	0.957	444.0	446.1	— 2.1
14 cent. model 1870, No. 2.	0.140	2.697	0.273	18.65	3.0	0.719	391.9	396.6	— 4.7
					3.5	0.838	431.2	434.9	— 3.7
					4.0	0.958	472.0	470.3	+ 1.7
14 cent. model 1870, No. 1, transformé.	0.140	2.560	0.273	18.65	3.0	0.719	387.9	393.1	— 5.2
					3.5	0.838	426.6	430.5	— 3.9
					4.0	0.958	466.6	465.4	+ 1.2
14 cent. model 1870, No. 1, transformé.	0.140	2.420	0.273	18.65	3.0	0.719	383.5	388.7	— 5.2
					3.5	0.838	424.0	425.4	— 1.4
					4.0	0.958	462.9	459.5	+ 3.4
14 cent. model 1870, No. 1, transformé.	0.140	2.281	0.273	18.65	3.0	0.719	378.4	383.8	— 5.4
					3.5	0.838	413.7	419.6	— 5.9
					4.0	0.958	458.3	453.2	+ 5.1
14 cent. model 1870, No. 1, transformé.	0.140	2.143	0.273	18.65	3.0	0.719	375.9	378.1	— 2.2
					3.5	0.838	414.6	413.3	+ 1.3
					4.0	0.958	456.2	446.1	+ 10.1
14 cent. model 1870, No. 2, transformé.	0.140	2.697	0.273	20.9	3.0	0.719	378.8	378.1	+ 0.7
					3.5	0.818	414.6	415.0	— 0.4
					4.0	0.938	447.4	449.0	— 1.6
14 cent. model 1871, No. 2.	0.140	2.697	0.273	23.3	3.0	0.719	366.1	361.1	+ 5.0
					3.5	0.818	400.5	396.7	+ 3.8
					4.0	0.938	428.0	429.5	— 1.5
19 cent. model 1870, No. 1.	0.194	3.002	0.512	62.5	10.0	0.661	393.3	390.6	+ 2.7
					12.5	0.826	444.6	446.4	— 2.2
					15.0	0.991	492.2	498.4	— 6.2
19 cent. model 1870, No. 1.	0.194	3.002	0.512	76.0	12.5	0.826	411.8	411.2	+ 0.6
					13.5	0.892	428.7	431.0	— 2.3
					14.5	0.958	446.4	450.4	— 4.0
					15.0	0.991	453.5	459.9	— 6.4
24 cent. model 1870, No. 24.	0.242	3.445	0.763	144.	12.0	0.342	253.3	250.9	+ 2.4
				ogival	16.0	0.456	306.6	302.3	+ 4.3
					20.0	0.570	350.2	348.3	+ 1.9
					24.0	0.684	393.2	390.6	+ 2.3
					28.0	0.798	432.0	431.4	+ 0.6
24 cent. model 1870, No. 24.	0.242	3.445	0.763	144.	12.0	0.342	253.9	250.9	+ 3.0
				cylindr.	16.	0.456	303.4	302.3	+ 1.1
					20.	0.570	350.0	348.3	+ 1.7
					24.	0.684	390.5	390.9	— 0.4
					28.	0.798	428.8	431.4	— 2.6
24 cent. model 1870, No. 24.	0.242	3.445	0.763	120.	12.	0.342	273.0	274.6	— 1.6
					16.	0.456	332.3	329.3	+ 3.0
					20.	0.570	379.5	378.1	+ 1.4
					24.	0.684	427.2	423.4	+ 3.8
					28.	0.798	467.4	466.5	+ 0.9
24 cent. model 1870, No. 1.	0.242	3.445	0.763	96.	12.	0.342	300.1	305.6	— 5.5
					16.	0.456	363.0	364.6	— 1.6
					20.	0.570	420.6	417.2	+ 3.4
					24.	0.684	469.2	465.9	+ 3.3
					28.	0.798	512.5	512.4	+ 0.1
24 cent. (steel), No. 1	0.242	4.036	0.796	144.	12.	0.333	262.7	263.4	— 0.7
				cylindr.	16.	0.444	312.3	314.5	— 2.2
					20.	0.556	360.4	363.1	— 2.7
					24.	0.667	396.6	407.7	— 11.1
					28.	0.778	434.9	449.8	— 14.9

58. *Force and time of combustion.*—Suppose that the grains of a charge may, on the average, be considered spheres; then (68) becomes applicable, and the cofficients A and B become

(101) $$A = 3^{\frac{1}{3}} P \left(\frac{f}{\tau} \right)^{\frac{1}{3}}, \quad B = \frac{Q}{\tau};$$

and the numerical values of A and B having been already determined, we may find f and τ by the relations

(102) $$\tau = \frac{Q}{B}, \quad f = \frac{\tau}{3} \left(\frac{A}{P} \right)^3.$$

Taking $A = 365.5$, $B = 37.07$, with the values of P and Q from (93) we have

$$\tau = 0.00994, \quad f = 45800.$$

These values are only a first approximation; and, although the question has no great practical importance, we shall find a closer approximation by taking account of the third term of (53).

59. *Influence of the third term of the formula for velocities.*—The term is as follows:

$$\left(3c - \frac{11}{6} b^2 \right) A^{-\frac{2}{3}} u^{\frac{5}{3}}.$$

Replacing c and b by their values (67), A by its value (45), and taking $\theta = \frac{1}{11}$, we find

(103) $$-R \left(\frac{m}{f \varpi} \right)^{\frac{1}{3}} \left(\frac{u}{\tau} \right)^{\frac{5}{3}},$$

R being equal to about .05.

The following table contains the calculation of this term for the various cases with the 14 cent. gun:

ϖ Kil.	No. 1	No. 4	No. 2
2.0	15.6		
2.5	14.4	14.2	
3.0	13.6	13.4	13.1
3.5		12.7	12.5
4.0			11.9

For the 24 cent. gun (projectile of 144 kilos), with charges of

	12,	16,	20,	24,	28 kilos,
we find	18.5	19.5	20.7	22.3	24.6

These values cannot be neglected, but their variations in the same gun may be nearly; because, in practice, the ratio $\frac{p}{\varpi}$ of the weight

of the projectile to that of the charge varies very little, and we may therefore replace it by a mean value.

Taking, for example, $\frac{p}{\varpi}=4.5$, and calculating the corresponding value of $\frac{m}{\varpi}=\frac{p}{\varpi g}$, we reduce the third term to the value,

$$-R\left(\frac{u}{\tau}\right)^{\frac{5}{3}},$$

R being equal to .00108.

60. *Corrected values of f and τ for Wetteren powder.*—Consequently, for spherical grains, writing the third term, the formula for velocity becomes,

$$(104) \qquad v=A\left(\frac{f\varpi u}{m\tau}\right)^{\frac{1}{3}}\varepsilon_1\varepsilon_2-Q\frac{u}{\tau}-R\left(\frac{u}{\tau}\right)^{\frac{5}{3}};$$

the relation $\frac{Qu}{\tau}=Bu$, which previously was used in calculating τ, is now replaced by

$$(105) \qquad Bu=\frac{Qu}{\tau}+R\left(\frac{u}{\tau}\right)^{\frac{5}{3}}.$$

For the 24 cent. gun we have found $Bu=127.7$. Substituting in the preceding equation, we find, by successive approximations,

$$\tau=0.0116, \quad f=53600.$$

61. This constant f is the force of the powder, that is to say the pressure on unit surface when unit weight is burned in unit volume. We have given (Part I, Chapter II, No. 17) a theoretical determination of this quantity. We have:

$$(106) \qquad f=\frac{2}{5}EQ\varepsilon,$$

where

E is the mechanical equivalent of heat;

Q the heat of combustion;

ε the weight of permanent gas given by the combustion of unit weight of powder.

In the place cited, the forces of the various powders made in France are given, and, having stated (what is confirmed by experiment) that these forces are about the same, notwithstanding the differences in proportions and in manufacture, we concluded that the mean value of this element may be fixed at 5290 atmospheres for a kilogram detonating in a liter. Taking the kilogram and meter for units, this corresponds to

$$f=54600;$$

this value does not sensibly differ from the one which results from an analysis of observed facts with guns.

This close agreement is worthy of attention; it will perhaps be considered sufficiently close to be accepted as showing that ballistic results, far from being in contradiction to thermodynamic theory, give additional strength to that theory.

62. *Determination of the velocity of cooling.*—The meaning of the coefficient γ, which has been found equal to 0.65, is given by (93),

$$\gamma = \frac{\pi a h}{q\alpha}$$

α having the value in (83). For spherical grains, $\alpha = \frac{3}{\tau}$, and consequently

$$\gamma = \frac{\pi a \tau h}{3q}.$$

We have then

$$h = \frac{3q\gamma}{\pi a \tau},$$

for the velocity of cooling by the walls of the gun corresponding to the mean temperature of the powder gas. We have

$$\tau = 0.0116, \qquad q = 784,^*$$
$$a = 0.10,^\dagger \qquad \gamma = 0.65,$$

and hence $h = 420000$ about.

This is the flow, in calories, per second per square meter.

This number is very large; but it does not seem inadmissible when we recollect the high temperature of the gas, and the physical laws which govern the cooling.

Although there are no experiments which would enable us to fix with precision the thermic changes, we may yet obtain an approximate idea by applying Dulong and Petit's law to recent experimental results, and particularly to those obtained by Mr. Donald McFarlane,‡ in a series of researches intended to establish the conductibility of bodies in absolute units. He measured, in calories, and for unit surface, the velocity of cooling of a copper sphere in damp air. Twelve determinations were made, for increments of 5°, from 5 to 60 degrees centigrade.

* This number is the mean of those determined by experiment for cannon powder, and powder called B (See Part I, Chapter II, No. 18).

† This value results from (83), by putting $a = \frac{1}{11}$.

‡ Proceedings of the Royal Society, Vol. XX, p. 90.

These limits are narrow; but if we admit, following Dulong and Petit, that the velocity of cooling corresponding to a difference θ of temperature is represented by a formula of the form

$$h = M(a^\theta - 1),$$

(M being a constant depending upon the circumstances of the cooling, and a a constant always equal to 1.0077), we may determine M from the results quoted.

Taking for units the meter and second, they are very well represented by the formula

$$h = 241\,(a^\theta - 1),$$

which may be taken as

$$h = 241 a^\theta,$$

when θ is large.

In these conditions, if $\theta = 973$, the value of h becomes the same as has been found.

63. It is important also to notice that, when θ varies, the corresponding variations of h are large. Consequently, the *mean value* used in the approximate evaluation of the effect of cooling in a gun should vary with the mean temperature produced in the gun. We have taken it the same in guns of different caliber, because the conditions of fire do not differ much, and because this element appears only in a relatively small term.

On the contrary, in small arms, the surface of cooling is relatively much larger than in great guns; and the temperature must therefore be lowered more. Consequently, the value of h in this case may be much smaller; and it should be made the object of experiment.

64. We conclude, from what precedes, that the formulæ deduced from thermodynamic theories, represent the actual effects of powder more accurately and throughout a greater range than do empirical formulæ.

We shall make, in the future, new applications to field guns and small arms. We shall also show how the characteristic elements of a powder may be deduced from a small number of experiments.

In a Third Part we shall take up the study of the circumstances upon which variations of pressures in guns depend.

Part III.

NEW RESEARCHES ON THE EFFECTS OF POWDER.

Preface.

I. In a memoir printed in 1875, I attempted to establish formulæ giving the initial velocity of a projectile as an explicit function of the elements of fire, basing the deduction upon the theory of thermodynamics. The results which I obtained appear to agree with facts; but, in consequence of certain restrictive hypotheses, they give only an approximation with which it is unsatisfactory to conclude, especially when we desire to study the law of the variation of pressure.

II. I assumed, to establish the equation of motion:

1st. That all the products of combustion of the powder were in the state of gas or vapor.

2d. That we may approximately substitute for the actual condition of these products a condition in which all parts of the gaseous mass have a temperature and density equal to the mean of the mixture.

3d. That the velocity of combustion of the powder is constant during the phenomena.

Thus from the first two hypotheses I have calculated the pressure on the projectile and the work done, by applying the laws of Mariotte and Gay-Lussac to the entire products of combustion, as if they were in the *static* state. If we admit the third hypothesis, the law of the combustion of a grain is given by formulæ similar to those of Piobert.

III. Since my memoir was prepared, Noble and Abel have published their important researches upon the combustion of powder in a closed vessel. These seem to indicate that a part of the products of combustion are in the solid state, in the ordinary conditions of their formation. Moreover, these products are in *motion* during the entire phenomenon, and it is necessary, in evaluating the external work, to take account of these internal motions, which will vary the density and temperature throughout the gaseous mass.

Consequently, the first two hypotheses seem to be insufficient. The third is certainly inexact; and, although we may admit, as an approxi-

mation, a value of the velocity of combustion which is considerably greater than that in free air, yet it is clear that, in a rigid analysis of the effects of powder in a gun, we must take account of the law by which the velocity of combustion varies with the pressure.

Finally, the method adopted, in my last memoir, to integrate the equation of motion leaves some doubt as to the degree of precision obtained; it is also subject to conditions which make it inapplicable to points near the origin of motion; and we therefore cannot deduce from it the law of pressures at the point where these latter are highest.

IV. For these reasons I have thought it would be of interest to undertake again the solution of the questions I have already treated, correcting and completing the data wherever possible. I have been able also, at the same time, to render the analytical considerations by which I deduce from the theory its various consequences more simple and rigid. These new researches will reproduce some results already reached, but they also furnish others which seem likely to throw some light on the complex subject we have in hand.

V. After discussing, in the first chapter, the results of the last experiments of Noble and Abel, I examine in Chapter II how the general equation may be modified so as to include the results of these experiments.

This modification may be made either by supposing, as do Noble and Abel, that the solid and gaseous products are always in equilibrium as to temperature; or, following Bunsen and Schischkoff, that the solid products continue at the temperature of combustion, and that the heat of the gaseous parts only is transformed into work.

In each hypothesis, the form of the fundamental equation is the same; the values of the coefficients changing, however. The same equation also holds when we take account of the internal motions, whose disturbing influence, evaluated by the new theory of gases, would appear to have a less value than some authors suppose.

This equation, from which flow the consequences which govern the velocities and pressures, is the one obtained by M. Resal in his *Researches on the Motion of Projectiles.*

Chapter III treats of the combustion of powder under variable pressure. The law connecting the velocity of combustion and pressure is not yet known. If we suppose, however, as a first approximation, that the velocity is proportional to a positive power of the pressure, we may represent the combustion of the charge in the variable

pressure of the expansion analytically, and thus establish the equation, having taken account of all the conditions.

Chapter IV is devoted to the integration of this equation. The integration is effected by series, by the aid of certain functions defined by a system of differential equations. These functions I have called *auxiliary;* they are purely numerical and entirely independent of the elements of fire, and tables of their values similar to those of logarithms may be computed.

In the fifth and last chapter, the methods of making the calculations will be presented.

VI. I thus obtain new formulæ giving the velocity and pressures, and I deduce from these the laws by which these quantities depend, not only upon the various elements of fire, but also upon the nature of the powder and the form of grains.

Among the results obtained I will mention the calculation of the maximum pressure produced in a gun from the following data, whose determination can all be made in a laboratory:

1st. The heat of combustion of the powder.

2d. The volume of permanent gas which is produced.

3d. The velocity of combustion in free air.

The values which we shall thus reach agree exactly with those given by direct measurement by pressure gauges.

CHAPTER I.

On the Pressure produced by the Powder Gases in a Vessel whose Capacity remains constant.

1. MM. Noble and Abel have recently communicated (1876) to the Academy of Sciences, the summary of important researches on the combustion of powder. Admitting the results of these learned experimenters, that which relates to the pressures developed by the combustion of the powder in a closed vessel is particularly remarkable. It results, in fact, from the measure of the pressures that one is able to explain the facts observed, by supposing:

1st. That a part of the products of combustion is in a solid state.

2d. That the pressure due to permanent gases only can be calculated after the law of Mariotte, by deducting from the volume of the envelope that of the solid residue.

2. The calculation of the pressures, under this hypothesis, is done in the following manner: Let

$C =$ the volume of the vessel or place of combustion.
$\varpi =$ the weight of the powder burned.
$T_0 =$ the absolute temperature of the products of combustion.
$\alpha =$ the volume at this temperature, of the solid residue furnished by the combustion of one kilogram of powder.
$v_0 =$ the volume (at zero centigrade, and under the normal atmospheric pressure), of the permanent gases of a kilogram of powder.

The permanent gases produced by the charge ϖ of powder at T_0 occupies a volume equal to $C - \alpha\varpi$. In order to find the corresponding pressure, it is necessary to apply the laws of Mariotte and Gay-Lussac, observing that the same gases under the normal pressure p_0 and at 273° of absolute temperature occupy a volume equal to $\varpi\, v_0$; we have then

$$\frac{p}{p_0} = \frac{\varpi v_0}{C - \alpha\varpi} \cdot \frac{T_0}{273},$$

or better,

$$p = f\frac{\varpi}{C - \alpha\varpi}, \tag{1}$$

putting for brevity,

$$f = \frac{p_0 v_0 T_0}{273}. \tag{2}$$

We can also introduce the *density of loading*, that is to say, the ratio $\Delta = \frac{\varpi}{C}$ of the weight of the powder to the capacity of envelope, and write,

$$p = \frac{f\Delta}{1 - \alpha\Delta}. \tag{3}$$

3. *Force of the powder.*—The quantity f defined by the relation (2) represents the pressure of the permanent gases of a kilogram of powder, occupying, at the temperature of the flame, a volume equal to unity, which exacts the condition that in taking account of the volume of the solid products, the volume of the envelope should be $1 + \alpha$.

We will call this quantity the *force of the powder.*

In a preceding work, supposing with several other authors that the products of combustion of powder, and more generally of any explosive substance, were totally converted into gases, at the temperature of the explosion, we have called the force of the explosive substance the

pressure developed by the unit of weight of the substance burning in the unit of volume.

This definition accords with the preceding, since, under this hypothesis, the volume a of the solid residue becomes zero; but it will be seen that the new definition is more general.

4. The results of the English experiments accord, in fact, very well with formula (3). MM. Noble and Abel have verified this with the pressures which they obtained by burning pebble powder in a closed vessel, the densities Δ varying by increments of 0.1 from $\Delta = 0.1$ to $\Delta = 1.0$.

The summary of their memoir does not mention the values admitted for the values of the constants f and a. These values seem to have been calculated by the aid of the pressures which corresponded to the values $\Delta = 0.6$ and $\Delta = 1$.

We have calculated these quantities by using in their determination all the results observed, using French units. We have found:

$$a = 0.6833 \qquad (4)$$
$$f = 219300,$$

the units being the *decimeter and the kilogram.*

The following table shows the pressures measured, the pressures calculated by formula (3), and the corresponding differences.

We have divided the pressures by 100, consequently in the table the pressures are in *kilograms per square centimeter.*

Densities.	Pressures.		
Δ	Measured.	Calculated.	Differences.
0.1	231	235	− 4
0.2	513	508	+ 5
0.3	839	828	+ 11
0.4	1173	1207	− 34
0.5	1684	1666	+ 18
0.6	2266	2230	+ 36
0.7	3006	2943	+ 63
0.8	3942	3869	+ 73
0.9	5112	5127	− 15
1.00	6567	6926	−359

The differences are not important, and since they do not seem to follow any law, they may be imputed to errors of experiment; besides, the account before mentioned does not give any detail of the method adopted for the measure of the pressures, and it is impos-

sible to discuss the results with exactness. It is likely that the experiments on the pressure of the gases of the powder in a closed vessel are those that were described by Captain Noble in a lecture before the Royal Society of Great Britain, or, at least, that they were determined in the same manner, that is, by *crusher gauges*, and the readings of these instruments being open to discussion, the results found should be accepted with some reserve. We add that the results differ completely from those which Rumford has deduced from his experiments.

In the meantime, formula (3) represents the facts with an exactness such that it is allowable to consider as very plausible the hypothesis according to which the products of the combustion of the powder will be, *under certain circumstances*, partly solid and partly gaseous. The pressure observed being due to the permanent gases alone, may be calculated by Mariotte's law, taking into account the volume occupied by the solid residue.

We show, in the following chapter, how, under this hypothesis, the equation of the movement of the projectile in the interior of a gun may be established.

5. *Temperature of the products of combustion.*—The value of f being determined by experiment, we deduce from it by equation (2) the value of T_0. We have, in fact:

$$T_0 = \frac{273 \cdot f}{p_0 v_0}.$$

According to MM. Noble and Abel, the value of v_0 was 280 litres for the powder experimented with. By making

$$f = 219300$$
$$v_0 = 280$$
$$p_0 = 103.33$$

we find for the absolute temperature of the gases

$$T_0 = 2070°$$

6. In order to calculate this temperature theoretically, it is necessary to know:

1st. The heat lost by the products of the combustion of the unit of weight of powder without production of exterior work by being lowered from the temperature T_0 of combustion to a determined temperature, say zero centigrade or 273° of absolute temperature.

2d. The mean specific heat of the products of combustion between these limits of temperature.

In fact, designating by Q the heat of combustion, and by c the specific heat, we have the relation:

$$Q = c(T_0 - 273),$$

whence

$$T_0 = 273 + \frac{Q}{c}.$$

The heat of combustion can easily be determined by the burning of powder in a calorimeter. MM. Noble and Abel found it equal to 705 *calories* (French units of heat) for the experimental powder.

With regard to the specific heat, it is unknown. MM. Bunsen and Schischkoff have admitted the value $c = 0.185$ for the products of combustion of a powder similar to our sporting powder. But this quantity corresponds to a temperature nearly the mean atmospheric temperature, and, following MM. Noble and Abel, it should vary, *increase*, probably, with the temperature.

Therefore, in default of more precise data, we admit the value $c = 0.185$ with $Q = 705$, and we find

$$T_0 = 4080°,$$

that is to say, a value nearly double that which has been deduced from the measure of the pressures. One would be led to admit, then, that the mean specific heat has a value nearly double that which MM. Bunsen and Schischkoff have adopted, and, consequently, since the specific heat of the gases under constant volume is independent of the temperature, that the specific heat of the solid residue at the temperature of combustion is more than double what it is at ordinary temperatures.

This result may seem excessive. We shall see later, however, in studying the cooling of the gases by the envelope, that one can explain the difference between the theoretic temperature and that deduced from the measure of the pressures, without necessarily admitting this enormous variation of specific heats.

7. *Volume of the solid residue at the temperature of combustion.* The coefficient α, the value of which is determined (4), represents the volume in cubic decimeters, at T_0, of the solid products of combustion of a kilogram of powder. Also, after MM. Noble and Abel, the volume of these products at ordinary temperature is 0.3, and their weight is 0.57 kilogram.

It is easy to conclude from these numbers and from the value $\alpha = 0.6833$:

1st. That the mean coefficient of cubic expansion of the solid residue between the temperature 273° and 2070° is 0.000624, or $\frac{1}{1600}$ nearly;

2d. That their specific weight at the temperature $T_0 = 2070°$ is equal to 0.903.

This last result does not agree with one determined by MM. Bunsen and Schischkoff. These experimenters have, in fact, found, by a method which seems to be a direct experimental determination, that the specific weight of the solid residue is 1.520 at the temperature of 2808°. It seems difficult, at this stage of our knowledge, to decide which of these two numbers is the nearer the truth.

It is, however, to be remarked, that the value $\frac{1}{1600}$ found for the coefficient of expansion notably exceeds analogous coefficients which correspond, in the ordinary limits of determinations, to the greater number of solid bodies. It may then be possible that this coefficient was really too large. The same may be true of α, the coefficient which served to determine it. We shall see, in fact, that an error of this kind can result from the cooling of the products of combustion by the wall of the vessel enveloping them.

8. We will close this discussion with a remark on the comparative volumes of the powder and the solid residue produced by the combustion. The volume of a kilogram of powder of a density 1.8 is $\frac{1}{1.8} = 0.55$. The volume of the solid residue resulting from its combustion is 0.68, according to MM. Noble and Abel, and 0.44 according to MM. Bunsen and Schischkoff, and the volume of the powder is somewhere between these two values. One may conclude from this, that if the solid residue of the combustion of the powder is formed under the same conditions as those of actual service, it would not be a great error to suppose that the volume of the residue, at the temperature of the flame, is equal to that of the powder itself. In the following chapter the utility of this remark will be manifest.

9. *Effect of the cooling of the products of the combustion of powder by the wall of the envelope.*—It has generally been supposed, in theoretical researches on the effects of powder and other explosive substances, that the cooling of the products of combustion by the wall which enveloped them could nearly always be neglected. But this effect cannot be neglected.

We have referred in our preceding work to the calorimetric experiments by which M. Saint-Robert ascertained that, in firing a gun, the

heat absorbed by the walls of the bore could be taken as nearly one-fourth the heat of the combustion of the charge.

The loss of heat, relatively less in guns of large calibre, is certainly a sensible quantity, and Captain Noble, in a lecture on this subject, is disposed to attribute to this cause considerable losses of work observed in certain experiments.

M. Berthelot also estimates that, in the application of processes which we arrange to produce very high temperatures, a large proportion of the living calorific force is lost through the wall of the envelope. This eminent chemist expresses himself as follows, and adds that the facts which support the statement will perhaps not be without interest for the study of the reactions produced by the combustion of powder in the bores of guns:

" L'existence des hautes températures en principe et la possibilité de les réaliser, me paraissent devoir être distinguées avec soin.

" En principe, nos théories actuelles indiquent qu'une masse gazeuse donnée peut acquérir une force vive indéfiniment croissante, c'est-a-dire une température illimitée . . . . .

" Mais, en fait, il se peut que l'intensité des radiations de toute nature augmentant avec une extrême promptitude à mesure que la température s'élève, et par suite les déperditions de la force vive qui se communique aux milieux environnants devenant de plus en plus considérables, rendent irréalisable toute température qui passerait une limite voisine de 2500 ou 3000 degrés observés dans les expériences de M. Sante-Claire Deville."

10. It seems to us probable that in all the circumstances of the combustions of the powder, the intensity of the thermic state realized is such that, in spite of the brevity of the phenomenon, the temperature can be lowered considerably in an extremely short time, and that perhaps to this rapid lowering of the temperature, varying with the mass of the powder, the surface of the envelope, and the period of combustion, may be attributed the difference, which the results present, of various authors who have sought to measure the pressure of the powder gases in a closed vessel.

We submit, while on this subject, some considerations, which without pretending to a rigorously exact determination, will serve, we believe, to give a notion of what these perturbing influences may be.

11. We consider a weight ϖ of powder burning in a closed vessel. The combustion of the powder is not instantaneous; it is done progressively, so that after a time t counted from the beginning of igni-

tion, the quantity of powder burned is a function $F(t)$ of which the form depends upon the physical qualities of the powder and upon the circumstances of combustion.

During combustion the envelope absorbs heat, and, after the time t, the temperature T of the products of combustion is less than T_0, which would have been the temperature had combustion taken place instantaneously. We will endeavor to express this difference. To this end, denote by

σ the total surface of the envelope,

h the velocity with which the heat is imparted for a unit of surface of the wall of the envelope,

The heat absorbed by the envelope after the time t is: $\sigma \int_0^t h.dt.$

Again, the heat lost by the weight $F(t)$, the temperature of the products of which is lowered from T_0 to T, is $cF(t)(T_0 - T)$, c being the mean specific heat under constant volume.

We have then:

$$cF(t)(T_0 - T) = \sigma \int_0^t h.dt. \tag{5}$$

The coefficient of cooling h is a function of the temperatures of the products and of the envelope, vanishing with their difference.

If one admits that the cooling takes place by radiation from the products of combustion through a superficial layer of the envelope, and that this radiation follows the law of Dulong and Petit, we are led to put

$$h = H\varepsilon\varepsilon'(a^T - a^{T_1}), \tag{6}$$

designating by,

T the absolute temperature of the products of combustion,

T_1 that of the envelope;

ε the emissive power of the products of combustion;

ε' the absorbent power of the substance of the envelope;

a is a constant always equal to 1.0077;

H is a constant, common to all bodies, and of which the value is 0.000237, if we take for units the decimeter and the second, the emissive and absorbent powers being referred to those of lampblack. The unit of heat is the *calorie* (the quantity of heat necessary to raise the temperature of a kilogram of water one degree centigrade).

NOTE I.—1. The numerical value adopted for the constant H of formula (6) Chapter I, has been deduced from the results of experiments by Dulong and Petit, in their researches on the laws of cooling. Consider a body at the absolute temperature T, cooling in an enclosure to the temperature T_1. Calling σ its

limiting surface, the quantity of heat which traverses this surface during an infinitely small time dt is $h\sigma dt$, h being the quantity defined by formula (6) before cited.

If then we designate by p the weight of the body, and by c its specific heat, the corresponding fall in its temperature is:

$$dT = \frac{h\sigma}{pc} \cdot dt,$$

it follows that the thermometric velocity of cooling is

$$h' = \frac{h\sigma}{pc}.$$

Or better, replacing h by its value,

$$h' = H\frac{\sigma\varepsilon\varepsilon'}{pc}(a^T - a^{T_1}). \tag{1}$$

2. Suppose, in particular, that the body, the cooling of which we are observing, is a sphere of radius r, Δ being the specific weight of the substance, we have

$$\sigma = 4\pi r^2,\ p = \frac{4}{3}\pi r^3\Delta,\ \frac{\sigma}{p} = \frac{3}{r\Delta}.$$

Consequently, putting $T = T_1 + \theta$, the formula (1) becomes,

$$h' = H\frac{3\varepsilon\varepsilon' a^{T_1}}{cr\Delta}(a^\theta - 1). \tag{2}$$

3. This being granted, Dulong and Petit have studied the cooling of a mercurial thermometer in an enclosure coated with lampblack to the temperature of zero centigrade.

The bulb of the thermometer was 6 centimeters in diameter, and one can, neglecting the cooling of the glass, apply the calculation to the cooling of a sphere of mercury of a radius of 3 centimeters, by taking for the value of the superficial emissive power the quantity $\varepsilon = 0.8$, which is very nearly that of glass.

Under these conditions, the numerical value of the elements which enter into formula (2) are, taking for units the decimeter and the kilogram:

$\varepsilon = 0.8$	$T_1 = 273$	$r = 0.3$
$\varepsilon' = 1.$	$c = 0.0333$	$\Delta = 13.596$

Under these conditions the experiment gave for the velocity of cooling per minute: $h' = 2.037\,(a^\theta - 1)$
or per second $h' = 0.03395(a^\theta - 1)$.

Comparing this value with formula (2) we deduce from it the value $H = 0.000237$.

12. In consequence of the absorption of heat, the temperature T_1 of the envelope is raised during combustion, which fact tends to diminish the velocity of loss of heat by the products of combustion. But the law of this heating is entirely unknown, and we are obliged to neglect it, supposing that T_1 remains always less than T.

In consequence of this hypothesis, which gives a superior limit to the loss of heat, relation (6) reduces to the following:

$$(7) \qquad h = H\varepsilon\varepsilon' a^T,$$

and equation (5) should be:

$$(8) \qquad cF(t)(T - T_0) = H\varepsilon\varepsilon'\sigma \int_0^t a^T . dt,$$

or

$$(9) \qquad zF(t) = k \int_0^t a^{-z} . dt,$$

designating by z the fall $T_0 - T$ of the temperature, and putting for brevity

$$(10) \qquad k = \frac{H\varepsilon\varepsilon' \sigma a^{T_0}}{c} .$$

In equation (9), the relation which connects z and t, z can be found in an explicit form when we know $F(t)$.

13. If we suppose, for example, the combustion to be uniform, we have $F(t) = \varpi \frac{\tau}{t}$, ϖ being the weight of the powder and τ the period of its combustion.

Equation (9) is satisfied then by giving to z a value independent of t, and this value is obtained by solving the transcendental equation:

$$(11) \qquad \frac{\varpi z}{\tau} = ka^{-z}.$$

For any other law of combustion $F(t)$ can generally be developed following the powers of t in the form $F(t) = \varpi at(1 + \lambda t + \mu t_2 + \ldots)$ We develop z in the same manner by putting:

$$z = z_0 + z_1 t + z_2 t^2 + \ldots$$

and substituting in (8) we easily determine the coefficients. This calculation offers but little interest and we will not enter into details. The ideal case of a uniform combustion suffices also for our beginning, which, we repeat, is an approximate representation of the phenomenon more than an absolute measure, which the want of physical data does not permit us to enter upon.

Equation (11), which determines, in this case, the constant fall of the temperature, is solved easily by trial when we know the value of k. It suffices to put the equation in this form:

$$(12) \qquad \log z + z \log a = \log k + \log \tau - \log \varpi,$$

the logarithms are those of the common system. We find quickly, by the aid of tables, the value of z, which makes the value of the first member of the equation sensibly equal to the given value of the second member.

14. It is necessary in order to make the calculation to have a value at least approaching that of k, and to know, consequently, the coefficients ε, ε'. The first is the emissive power of the products of combustion: this element is absolutely unknown. It is known, however, that the flame, containing solid incandescent particles, has a considerable emissive power. In the absence of all precise data, we will make the calculation under the hypothesis that it has an emissive power equal to unity.

The absorbent power ε' depends upon the nature of the envelope. For polished iron we can take Leslie's number, $\varepsilon' = 0.15$. We will take finally for the specific heat of the products the value $c = 0.185$ admitted by MM. Bunsen and Schischkoff, and for T_0 the theoretical value of No. 6, $T_0 = 4080$ degrees.

Putting these values in (9) we find:

$$\log k = 9.874 + \log \sigma,$$

consequently equation (12) becomes

$$\log z + z \log a = 9.874 + \log \sigma + \log \tau - \log \varpi.$$

15. Suppose, in order to fix these ideas, that the combustion takes place in a cubic capacity of one decimeter. The surface σ is then equal to 6 (sq. dec.), and, giving to τ and to ϖ various values, we can calculate the corresponding values of z.

We give, in a table, the fall of temperature obtained in supposing:

$$\tau = 0.1 \quad 0.01 \quad 0.001 \quad \text{(seconds)}$$
$$\varpi = 0.1 \quad 0.5 \quad 1.0 \quad \text{(kilogram)}$$

Values of τ Seconds.	Values of ϖ (Kilogram). k 0.1 degrees.	k 0.5 degrees.	k 1.0 degrees.
0.001	1630	1440	1360
0.010	1910	1720	1630
0.100	2190	2000	1910

These results show that a fall of temperature in the neighborhood of 2000° is not improbable, and consequently we can conclude that the temperature of explosion is, perhaps, not very far from the theo-

retical value, and that the influence of the envelope alone prevents it from reaching that value. In all cases it is not necessary to admit, to explain the difference, a considerable variation of the specific heats.

16. For the same value of τ, the values of z vary with the weight ϖ of the powder burned; however, the variations should be very small, in order that formula (3) may be applicable, supposing f to be constant. But it is easy to see, then, that one would take a value too great of α.

Suppose, in fact, that it is desired to determine α by the aid of two experiments giving the pressures p_1 and p_2, corresponding to the values $\varDelta_1$, $\varDelta_2$ of $\varDelta$. The temperatures being different in the two cases, we have two different values f_1, f_2 of f. The relation (3) gives the two equations:

$$p_1 = \frac{f_1 \varDelta_1}{1 - \alpha\varDelta_1}, \quad p_2 = \frac{f_2 \varDelta_2}{1 - \alpha\varDelta_2}.$$

We find from them

$$\alpha = \frac{\dfrac{p_2}{\varDelta_2} - \dfrac{p_1}{\varDelta_1}}{p_2 - p_1} - \frac{f_2 - f_1}{p_2 - p_1},$$

an expression in which, f increasing with p, the second term is necessarily negative. The exact value of α is then less than that which we should have found had we supposed $f_2 = f_1$.

This result confirms the remarks which were made in the preceding (Nos. 7 and 8).

CHAPTER II.

General Equation of Motion in the Bore.

17. If we admit that a part of the products of combustion are in a solid state, in the ordinary conditions of the employment of powder in guns, we are led to modify in some respects the analysis by which we have already established the equation of motion upon the supposition that the entire products are in a gaseous state.

We may, in fact, assume two hypotheses, which include the truth probably. We may suppose that the solid products are always in equilibrium of temperature with the gas, and thus give up some heat which is transformed into work; or that the temperature of the solid products is constant during the expansion of the gas.

Following the first hypothesis, generally accepted by Noble and Abel, we have calculated (Part I, Chapter 3) the theoretical maxi-

mum work which the powder can perform. Bunsen and Schischkoff have, on the contrary, adopted the second hypothesis, and have calculated the work from the expansion of the permanent gases alone, supposing that the solid residues preserve always their initial temperature.

18. *First hypothesis.*—Suppose first, as in the preceding memoir (Part II, No. 3), that the heat lost by the totality of the products of combustion represents the external work $\mathfrak{C}$ according to the relation,

$$\text{(13)} \qquad \frac{\mathfrak{C}}{E} = cy\,(T_0 - T),$$

E being the mechanical equivalent of heat;

c the mean specific heat, in constant volume, of the products of combustion;

$y = F(t)$, their weight at the time t;

T their absolute temperature at any time; and

T_0 the temperature of combustion.

The pressure of the permanent gases is given by,

$$\text{(14)} \qquad p = \frac{p_0 v_0 y T}{273.\,V.},$$

V being the volume of the gas, and v_0 the specific volume of the gas of a kilogram of powder. Eliminating T between (13) and (14), we have,

$$\text{(15)} \qquad pV + 2\theta\,\mathfrak{C} = fy,$$

putting

$$\text{(16)} \qquad 2\theta = \frac{1}{273}\,\frac{p_0 v_0}{Ec},$$

f being the force of the powder, defined by (2) of the preceding chapter.

This equation is similar to (7) of Part II. It differs from this only in the value of 2θ; which is equal, when all the products are gaseous, to $n - 1$, n being the ratio of the two specific heats.

The general equation of motion may be deduced as in Part II (No. 5). It is as follows:

$$\text{(17)} \qquad (u + z)\frac{d^2u}{dt^2} + \theta\left(\frac{du}{dt}\right)^2 = \frac{fy}{m}.$$

The quantity z is defined by the condition that $\omega\,(u + z)$ represents the volume V occupied by the gas; this volume is composed of the following:

1st. The initial volume V_0 around the charge before the displacement of the projectile.

2d. The volume y_1, being that of the interstices between the grains in the fraction of the charge which is lighted.

3d. The cylindrical space ωu, corresponding to the displacement of the projectile.

When the gasification is complete we must add the volume of the powder burned; but, if there are any solid residues, we must take the excess of the volume of the powder over that of the residue formed by the combustion. If then we suppose these two volumes equal (Chapter I, No. 8), we may neglect this factor, and write

$$V = V_0 + y_1 + \omega u,$$

and, consequently,

$$z = \frac{1}{\omega}(V_0 + y_1).$$

When the inflammation is *instantaneous*, the volume $V_0 + y_1$ is always the same as that of the powder chamber, diminished by the volume of the grains. Consequently, the value of z will be constant.

This value may be put in the two forms,

$$z_0 = u_0\left(1 - \frac{\Delta}{\delta}\right) \tag{18}$$

$$z_0 = \frac{\varpi}{\omega}\left(\frac{1}{\Delta} - \frac{1}{\delta}\right) \tag{19}$$

(See Part II, No. 21), where

u_0 is the reduced length of the powder chamber, or the length of a cylinder of equal volume having ω, the cross section of the bore, as a base;

ϖ the weight of the charge;

ω the section of the bore;

Δ the density of loading;

δ the density of the powder.

We see that here the substitution of z_0 for z, adopted as an approximation in Part II, No. 23, to simplify the integration, becomes exact when we adopt the hypothesis of the solid residues.

19. *Second hypothesis.*—Suppose, secondly, that the gaseous products only change their temperature. Let ε be the weight of the gas of a kilogram of powder.

The weight y of powder burned in the time t gives a quantity εy of gaseous product; which, falling from T_0 to T, gives out a quantity of

heat $c_1 \varepsilon y (T_0 - T)$; c_1 being the specific heat, in constant volume, of the gaseous products of combustion alone. Consequently (13) is replaced by

$$\frac{\mathfrak{C}}{E} = c_1 \varepsilon y (T_0 - T).$$

The rest of the deduction in No. 18 remains the same; and (17) is the same if we write εc_1 in place of c in (16), which thus becomes

$$2\theta = \frac{1}{273} \cdot \frac{p_0 v_0}{E c_1 \varepsilon}. \tag{20}$$

Since v_0 is the reduced volume of a weight ε of permanent gas, the *specific* volume or volume of unit weight of the same gas is $\frac{v_0}{\varepsilon}$, and we have consequently

$$E = \frac{1}{273} \cdot \frac{p_0 v_0}{\varepsilon (c' - c_1)},$$

c' being the specific heat under constant pressure.

Note.—The above expression for E may be obtained by writing $\frac{v_0}{\varepsilon}$ for v_0 in (14) Part I.

If then we call n the ratio of the two specific heats $\frac{c'}{c_1}$, we have

$$\theta = \frac{n - 1}{2}, \tag{21}$$

as in the case where all the products are assumed to be gaseous.

20. In the two hypotheses, the equation of motion (17) has the same form, but the coefficient θ has different values. We shall now give these values in some particular cases.

First hypothesis.—The value of θ (16) depends upon the volume v_0 and the specific heat c. The first may be determined by experiment. We have elsewhere made this determination for the powders commonly used in France. The second is not known; we consider, however, that it is very nearly the same for all powders (Part I, p. 17); so that we may, without much error, adopt the value found by Bunsen and Schischkoff, $c = .185$.

The following table gives the values of v_0 and those corresponding of θ, for the principal powders.

Name of Powder.	v_0 (liters).	θ.
Sporting powder,	234	.0549
Cannon "	261	.0612
Fine-grained powder, called B	280	.0657

Second hypothesis.—In the second hypothesis we have $\theta = \frac{n-1}{2}$, n being the ratio of the two specific heats of the permanent gases. If we adopt the value $n = 1.4$, which is correct for the state of perfect gas, we have $\theta = \frac{1}{5}$; this is very much larger than the foregoing values.

21. It appears difficult to decide which of these two hypotheses is nearest the truth. In our first researches we admitted that the sensible heat of the totality of the products of combustion would be transformed into work; and this hypothesis was necessary, because we supposed that all these products were in the state of gas or of vapor. If, as the facts set forth in the preceding chapter seem to show, solid products really exist at the temperature of the flame, it is very unlikely that these products, whose emissive power is probably very considerable, would have always the same temperature. But it is possible that they radiate to the walls of the gun, and that the heat should be thus absorbed without greatly modifying the thermic qualities of the gas, whose emissive and absorbing powers are probably very small.

The second hypothesis does not then seem inadmissible. Noble and Abel reject it formally and consider that "the hypothesis of Bunsen and Schischkoff, that the effect on the projectile must be attributed to the permanent gases, without gain or loss of heat, is incompatible with observed facts."

To establish this incompatibility completely, and exhibit the partial, at least, utilization of the heat of the solid products, it would be necessary, it appears, to show that the effective work of a gun may exceed the mechanical equivalent of the sensible heat of the gases produced by the explosion of the charge. For, if the contrary takes place, we may suppose that the difference represents the effect of passive resistances, coolings, interior motions, or other causes of dissipation of energy.

Now, taking for our calculations the data determined in our experimental researches, we find that the theoretical maximum effect, calculated by the hypothesis of Bunsen and Schischkoff, is sensibly greater than the observed effects. Let us enter in some detail upon this question.

22. We have elsewhere remarked (Part II, No. 7) that the equation of motion (17) becomes directly integrable when the explosion is supposed instantaneous. We deduce from this a formula for velocity

which is not exact, since the combustion is progressive and not instantaneous; but which, as observed by Résal in his *Recherches sur le Mouvement des Projectiles*, cannot be very far from the truth, and should give, in all cases, a superior limit of the attainable velocity.

We may establish this formula in the two hypotheses, and compare the theoretical velocities which result with actual velocities. The following is the detail of the calculation:

Let $v = \frac{du}{dt}$, the velocity of the projectile at any time. The integration of (17) in the case of instantaneous explosion gives the relation

$$v^2 = \frac{f\varpi}{\theta m}\left[1 - \left(\frac{z_0}{u + z_0}\right)^{2\theta}\right]. \tag{22}$$

23. In the first hypothesis, f and θ having the values (2) and (16), we have

$$\frac{f}{\theta} = 2EcT_0,$$

or calling Q the heat of combustion of the powder (Part I, No. 3),

$$\frac{f}{\theta} = 2EQ.$$

Consequently, (21) becomes

$$v^2 = 2EQ\frac{\varpi}{m}\left[1 - \left(\frac{z_0}{u + z_0}\right)^{2\theta}\right]. \tag{23}$$

The exponent θ has, according to the powder used, one of the values in the table of No. 20.

24. In the second hypothesis, in consequence of (20), we find,

$$\frac{f}{\theta} = 2\varepsilon c_1 ET_0 = 2\frac{\varepsilon c_1}{c}EQ,$$

and, taking $\theta = \frac{1}{5}$, we have,

$$v^2 = 2\varepsilon\frac{c_1}{c}EQ\frac{\varpi}{m}\left[1 - \left(\frac{z_0}{u + z_0}\right)^{\frac{2}{5}}\right], \tag{24}$$

where

ε is the weight of the permanent of a kilogram of powder,
c the mean specific heat of all the products,
c_1 the specific heat, in constant volume, of the gaseous products.

For the powders used by Bunsen and Schischkoff, $c_1 = .164$, $c = .185$, $\frac{c_1}{c} = .887$; and we may use the figures approximately for the various usual powders.

25. Let us apply formulæ (23) and (24) to some particular cases. The following table gives the elements and result of the calculations.

Names of Elements of calculation units: decimeter and kilogram.	Small arm.	Cannon of 24.	Navy Cannon of 24 cm.
Diameter of the bore,	.175	1.53	2.42
Initial distance of the base of the projectile from the muzzle, u	9.80	27.91	34.45
Reduced length of the chamber, u_0	"	2.95	7.63
Density of loading, $\varDelta$	1.00	.537	.798
Reduced length of initial air-space, z_0	.0435*	1.92†	4.24‡
Weight of powder, ϖ	.0025	2.90	28.
Weight of projectile, mg	.036	24.0	144.
Heat of combustion, Q	849	795	795
Weight of the gas of one kilogram of powder, ε	.337	.412	.412
Velocity by (23) (meters)	494	482	560
" " (24) "	365	447	533
" observed "	275	334	432

Remarks.—The powders used are: 1st, sporting powder for the small arm; 2d, cannon powder (poudre à canon des pilons) for the cannon of 24; 3d, Wetteren powder (grains of 13 to 16 mill.) for the navy gun of 24 cm.

The results shown in this table may be thus summarized:

1st. The velocities calculated by (24) (that is, neglecting the transformation of the heat of the solid residues into work) are, in each case, very largely in excess of the true velocity.

2d. For the two large guns, the velocities calculated by the two formulæ differ little.

3d. For the small arm, where the length of the piece is proportionately greater, the velocity calculated by (23) is much greater than the other, and is more than double the true velocity.

It appears difficult to explain this. A considerable fraction of the heat, it is true, is lost to the walls of the gun, but this cannot exercise

* Calculated by (19).

† Calculated by (18).

‡ The proportions of the Wetteren powder are those of the regulation cannon powder; we have taken the same values of Q and ε for these two powders. The values used are those of our first researches on the force of explosive substances.

so great an influence. In fact, whatever might be the law of the absorption of heat, the effect of the heat lost is less than if that heat were to completely disappear at the origin of motion. We must then replace Q by $Q - Q_1$, and consequently multiply the velocities by $\left(1 - \frac{Q_1}{Q}\right)^{\frac{1}{2}}$; which will $= .865$, if we take $\frac{Q_1}{Q} = \frac{1}{4}$, following the experiments of Saint-Robert.

The velocities thus calculated are 428 and 316 meters; and the difference between the first of these and the true velocity, which is 275, is certainly too great to be attributed to the other causes of loss of velocity.

The calculation seems therefore to indicate that the heat of combustion of the charge is only partially utilized. It is possible, and even probable, that the temperature of the solid residues is not greatly lowered; or even that the heat which they give out, if they are cooled, does not sensibly heat the gases, and therefore is not transformed into useful work.

Finally, the hypothesis of Bunsen and Schischkoff, on the mode of utilization of the heat of the powder, seems applicable to the expansion of gas in guns. There is nothing to indicate, moreover, that this hypothesis may also be applied to the other modes of using powder; and, in particular, that it should be applied in calculating the theoretical maximum work of indefinite expansion. We may therefore adhere to the views expressed in Part I, p. 33.

26. *Influence of the proper motion of the products of explosion.*—It was assumed in Part II, No. 2, to establish the general equation of motion, that we may approximately substitute for the real state of the products of explosion, a fictitious state in which the entire mass of gas has the mean density and temperature of its different parts. Starting with this hypothesis, we have calculated the pressure upon the projectile and the external work done, according to the laws of Mariotte and Gay-Lussac, as if the products were in a static state.

We have thus analyzed the principal circumstances of the phenomena, making use only of some elementary notions of thermodynamics, which we have deduced from the laws of permanent gases. This analysis is incomplete, as it took no account of the motion of the products of combustion and of the unburned portion of the charge. We may, in the following manner, take account of this, according to the new theory concerning gases.

27. At any instant, let

$y =$ the weight of the products of explosion.

$\mu =$ the mass of the charge.

$d\mu =$ the mass of an element of the mixture formed by the burned and unburned fractions of the charge.

$x =$ the distance, a function of the time, which separates the element $d\mu$ from the bottom of the bore.

$T =$ the mean temperature of the products of combustion.

If the products of combustion are formed without proper sensible motion and without the production of external work, their temperature will always remain equal to T_0, the temperature of combustion. But, in consequence of internal motion, and of the work of expansion, their temperature will fall, and the heat given out by the weight y* of the products, falling from T_0 to T, represents half the living force of the charge and the external work produced.†

Equation (13) should then be replaced by the following,

$$Ecy(T_0 - T) = \mathfrak{C} + \frac{1}{2}\int\left(\frac{dx}{dt}\right)^2 d\mu. \tag{25}$$

Also, relation (14) between the pressure p upon the projectile, and the volume, weight and temperature of the products of combustion, must be modified as follows, to take account of the sensible internal motions:

$$pV = \frac{p_0 v_0}{273} yT - \int x \frac{d^2x}{dt^2} . d\mu. \tag{26}$$

NOTE I.—Equation (26) may be established by the aid of considerations similar to those which Clausius and Yvon-Villarceau have recently employed to establish some important theorems of general mechanics.

Consider a material system formed of the products of combustion, and let $d\mu$ be an element of the system. Let x be its distance at any time from the bottom of the bore, and X the component, parallel to this distance, of the force applied to it. We have

$$\frac{d^2x}{dt^2} . d\mu = X.$$

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* We here reason upon the hypothesis that the totality of the products of explosion are in equilibrium of temperature. If, on the contrary, we suppose that the temperature of the gaseous products alone is lowered by the expansion, we must, as in No. 19, replace c by εc, ε being the weight of the gas of a kilogram of powder, and c its specific heat.

† We neglect the internal work, which, in perfect gases, is considered to vanish, or to become so small that it may be neglected.

Multiplying by x, and summing the results thus obtained for all the elements of the system, we have

$$(1) \qquad \int x \frac{d^2x}{dt^2} \cdot d\mu = \Sigma xX.$$

Neglecting the internal forces, according to the theory of gases, the forces applied to the system are reduced to the reactions at the extremities of the mass; that is, to forces equal and opposite to the pressures upon the bottom of the bore and upon the projectile.

We need take no account of the first, for at that point x is zero. If, then, adopting the notation of No. 28, we call

$u + u_0$ the distance which separates the projectile from the bottom of the bore;

p the pressure, on unit surface, upon the projectile;

ω the cross section of the bore, supposed equal to that of the projectile;

the second member of (1) reduces to $-(u + u_0)\,\omega p$, that is, to $-Vp$, V being the volume occupied by the products of explosion. We have then

$$(2) \qquad pV = -\int x \frac{d^2x}{dt^2} \cdot d\mu.$$

2. We must distinguish, in the second member, between the parts which represent the sensible motion, and those which represent the rapid vibratory motions which, according to present theories, constitute the thermic state of the system. According to these theories, each point oscillates around a mean position, and we have $x = x_0 + a$,

x_0 being the abscissa of the mean position, and a the variable displacement in the vibratory motion. Consequently

$$(3) \qquad x\frac{d^2x}{dt^2} = x_0\frac{d^2x_0}{dt^2} + a\frac{d^2x_0}{dt^2} + x_0\frac{d^2a}{dt^2} + a\frac{d^2a}{dt^2}.$$

3. Consider the *mean values* of the terms in the second member in an interval of time, which is very great compared to the period of thermic motion, but very small in absolute value, so that the variations of x_0 and $\frac{d^2x_0}{dt^2}$ may be neglected. Observing that the means of a and $\frac{d^2a}{dt^2}$ are zero, we may write (3) in the form,

$$x\frac{d^2x}{dt^2} = x_0\frac{d^2x_0}{dt^2} + a\frac{d^2a}{dt^2},$$

recollecting that the second member is to be replaced by its mean value.

We have thus,

$$pV = -\int a\frac{d^2a}{dt^2}\,d\mu - \int x_0\frac{d^2x_0}{dt^2}.$$

The second term represents the value to which pV is reduced when there is no sensible motion in the medium. Now, according to Gay-Lussac's law,

$$pV = \frac{p_0v_0}{273}\,yT.$$

Consequently, in the general case,

$$pV = \frac{p_0 v_0}{273} yT - \int x_0 \frac{d^2 x_0}{dt^2} d\mu.$$

Suppressing the subscripts, which are not necessary when we consider the sensible motions alone, we have (26).

Eliminating yT between (25) and (26), we find the relation,

$$(27) \qquad pV + \int x \frac{d^2 x}{dt^2} d\mu + 2\theta \left(\mathfrak{E} + \tfrac{1}{2} \int \left(\frac{dx}{dt} \right)^2 d\mu \right) = fy,$$

which replaces (14).

28. To deduce from this the equation of motion, we will call $u + u_0$ the distance of the projectile from the bottom of the bore; u_0 being its initial distance and u its displacement.

The distance x of any element is evidently less than $u + u_0$; also, if there are no *tourbillons intérieurs*, the velocity and acceleration of this element are less than those of the projectile; we may therefore write,

$$(28) \qquad \int x \frac{d^2 x}{dt^2} d\mu = a\mu (u + u_0) \frac{d^2 u}{dt^2},$$

$$(29) \qquad \int \left(\frac{dx}{dt} \right)^2 d\mu = a'\mu \left(\frac{du}{dt} \right)^2,$$

a and a' being coefficients less than unity.

Also, calling m the mass of the projectile, and z the quantity defined in No. 18,

$$(30) \qquad pV = m(u + z) \frac{d^2 u}{dt^2},$$

$$(31) \qquad \mathfrak{E} = \tfrac{1}{2} m \left(\frac{du}{dt} \right)^2.$$

Finally, putting

$$(32) \qquad \beta = \frac{u + u_0}{u + z},$$

formula (28) may be written,

$$(33) \qquad \int x \frac{d^2 x}{dt^2} d\mu = a\beta\mu (u + z) \frac{d^2 u}{dt^2}.$$

Recollecting the relations (33), (29), (30), (31), (27) becomes

$$(34) \quad (u + z) \frac{d^2 u}{dt^2} \left(1 + a\beta \frac{\mu}{m} \right) + \theta \left(\frac{du}{dt} \right)^2 \left(1 + a' \frac{\mu}{m} \right) = \frac{fy}{m}.$$

Such is the equation of motion of the projectile. It differs from the one already obtained only in the coefficients of the first member.

These coefficients are reduced very nearly to unity when the mass of the charge is very small compared to that of the projectile.

This condition is not realized in the ordinary circumstances of practice; the ratio $\frac{\mu}{m}$ is often equal, and sometimes superior, to $\frac{1}{5}$. The coefficients may, therefore, differ sensibly from unity.

To ascertain their value, it would be necessary to know the law by which the velocities and accelerations of the various elements of the charge vary. This was attempted by Lagrange, Poisson, and Piobert. The problem is too complex and difficult, however, for us to hope to attain results which would be practically useful.

Fortunately, the importance of its solution is only secondary, for it can be shown, that without making a complete calculation, (17), which was obtained by neglecting the internal motions, takes account of the most essential parts of the problem.

29. We remark first that, in the ordinary conditions of practice, the coefficients α and α' have smaller values than they would have if the entire charge was instantly gasified at the origin of motion.

At any given instant, the solid residues of the burned powder and the grains not yet burned are irregularly dispersed through the mass of gas, and are surrounded by it, so that the pressure on their surfaces is everywhere about the same. Their accelerations and velocities must, consequently, be small, and the corresponding elements of the integrals (28) and (29) will have an insensible value; these are therefore diminished.

Consider now their values if all the charge became gas at the origin of motion. Suppose that an element of the mass, perpendicular to the bore, had at all its parts the same velocity and acceleration parallel to the axis of the gun, without having other motion. Let ρ be the density of the element and dx its thickness. Its mass is $\rho\omega dx$, ω being the cross section of the bore; consequently (28) and (29) become

$$\omega\int x\frac{d^2x}{dt^2}.\rho dx \text{ and } \omega\int\left(\frac{dx}{dt}\right)^2.\rho dx.$$

30. To accomplish the integration, it is necessary to know the law by which the density, acceleration, and velocity of an element depend upon its position.

Piobert assumed that its velocity is proportional to its distance from the bottom of the bore. We have then,

$$\frac{dx}{dt}=\frac{x}{u+u_0}.\frac{du}{dt}. \tag{35}$$

Differentiating totally, with respect to t, we have,

$$\frac{d^2x}{dt^2} = \frac{1}{u+u_0}\frac{dx}{dt}\cdot\frac{du}{dt} + \frac{x}{u+u_0}\frac{d^2u}{dt^2} - \frac{x}{(u+u_0)^2}\left(\frac{du}{dt}\right)^2,$$

or, replacing $\frac{dx}{dt}$ by its value in (35)

$$(36) \qquad \frac{d^2x}{dt^2} = \frac{x}{u+u_0}\frac{d^2u}{dt^2}.$$

The law of accelerations is therefore the same as the law of velocities.

The density ρ varies throughout the mass according to an unknown law. But the variation is probably not great, and we may neglect it in the calculation of terms of small numerical value.

In consequence of these hypotheses, we find,

$$\int x\frac{d^2x}{dt^2}d\mu = \frac{\rho\omega}{u+u_0}\frac{d^2u}{dt^2}\int x^2dx,$$

$$\int\left(\frac{dx}{dt}\right)^2 d\mu = \frac{\rho\omega}{(u+u_0)^2}\left(\frac{du}{dt}\right)^2\int x^2dx.$$

The integral $\int x^2dx$ must be taken between the limits 0 and $u+u_0$; its value is $\frac{1}{3}(u+u_0)^3$. Substituting in the two expressions above, and recollecting that $\rho\omega(u+u_0) = \mu$, we have finally

$$\int x\frac{d^2x}{dt^2}d\mu = \frac{1}{3}\mu(u+u_0)\frac{d^2u}{dt^2},$$

$$\int\left(\frac{dx}{dt}\right)^2 d\mu = \frac{1}{3}\mu\left(\frac{du}{dt}\right)^2;$$

and, consequently, comparing with (28) and (29),

$$\alpha = \alpha' = \frac{1}{3}.$$

These values may be considered a superior limit. A half at most of the charge becoming gas probably, their real values do not perhaps exceed $\frac{1}{6}$.

31. When the gasification is complete, β (32) becomes equal to unity. When the gasification is partial and progressive, we may also take $\beta = 1$. In fact, β approaches the value unity for increasing values of u. When u is very small, β differs from unity; but then, the mass of the gaseous products being very small, α and α' are very small and the value of these terms becomes small.

If in (34) we put $\alpha = \alpha' = \frac{1}{3}$, $\beta = 1$, we have

$$(37) \qquad (u+z)\frac{d^2u}{dt^2} + \theta\left(\frac{du}{dt}\right)^2 = \frac{fy}{m\left(1+\frac{1}{3}\frac{\mu}{m}\right)}.$$

This is essentially of the same form as (17), there being a slight change in the second member. We may consider this change as affecting the mass of the projectile, which, if we take $\frac{\mu}{m} = \frac{1}{5}$, should be increased by $\frac{1}{15}$th. If we take, (65) of Part II, the relative variation of the term depending upon m is $\frac{1}{45}$; it would be $\frac{1}{90}$ if we take $a = a' = \frac{1}{6}$, in accordance with the remark at the end of No. 30. In this last case, the variation of the velocity is only 5 or 6 meters.

32. The disturbances which result from the movement of the various parts of the charge appear then to be of small importance; we may then neglect them, and consider that (17) expresses the motion of the projectile correctly. It is also to be noticed that the effect of these motions being to diminish the value of the second member of this equation, has the same effect as diminishing the value of f, and this diminution may be considered a constant quantity, the ratio $\frac{\mu}{m}$ varying very little in the conditions of practice.

We may also, by a change in the value of f, take account of the cooling effect upon the gas of the walls of the gun; the effect of this is probably larger than that which we have just examined. Supposing then that f represents the force of the powder thus corrected, (17) becomes exact.

In this case, the datum *à priori* of the force of the powder appears nearly useless, as we do not know the correction which should be applied to take account of the various causes of loss of work. But we should not attach too much importance to this circumstance. It appears indeed very difficult, and we may add of no practical utility, to arrive at a theory which would enable us to compute any desired result, without certain data determined by experimentation in the same conditions. A theory which requires a small number of ballistic experiments for the determination of a single coefficient, and which will then enable us to calculate effects under other conditions, will, on the other hand, suffice for all practical purposes. The most important point is to establish the *form* of the relations which connects the obtained effects with the variables, and thus to avoid the use of empirical formulæ which may be incompatible with the nature of the laws they are intended to represent.

CHAPTER III.

Combustion of Powder under Variable Pressure.

33. In a previous paper,* was established the general form of the function by which we are able to represent the combustion of a charge of powder. The form of this function depends upon the particular manner in which the combustion is effected, in the different cases; the progessive ignition of the charge and the combustion of the grain. We shall only consider here the particular case in which the conditions of loading are such that the period of ignition may be neglected with respect to that of combustion. This case is realized in practice in consequence of the adoption of large-grained powder for guns of large calibre.

The combustion of the charge is then represented by the same function as the combustion of each grain. If we designate by ϖ the weight of the charge, $\psi(t)$ the fraction of one of the grains (supposed equal) constituting the charge which is burned after a time t, counting from the instant when the surface of the grain is reached by the flame, we have, for the weight of powder burned after a time t: $y = \varpi\psi(t)$.

34. In order to determine, for the various forms of grains, the function $\psi(t)$, we have admitted, with Piobert:

1st. That all the points of the surface of the grain are reached simultaneously by the flame.

2d. That the combustion of the material is propagated, *with a constant velocity*, normal to the surfaces in ignition.

The first of these hypotheses can be accepted without giving rise to sensible error; but the second is certainly not exact. We have heretofore stated † that, zero with the pressure, the velocity of combustion is a rapidly increasing function of the pressure of the medium in which the combustion takes place.

We have thus far neglected this circumstance in the calculation of velocities. In order to comprehend that the results thus obtained can be but little removed from the truth, it suffices to recall the following method which shows the development of useful work in a gun.

Starting from the beginning of ignition the interior pressure rapidly rises, and attains a maximum when the projectile is displaced a very small fraction of the length of the bore. It falls subsequently by

* Part II, chap. 2.

† Part II, 17.

amounts which, for progressive powders, are little different the one from the other for the greater part of the path of the projectile. It is during this last period of the phenomenon that the principal useful effect is developed. It is conceivable, then, that one can, with a certain approximation, attribute to the velocity of combustion a constant mean value, by taking, it being well understood, for this element a value different from that which is observed under the normal atmospheric pressure.

In these new researches we propose to study the initial movement; the influence of the pressure on the combustion is then dominating, and cannot be dispensed with.

35. We find in the "Memoires Scientifiques" of M. de Saint-Robert, the complete summary of the experiments which have been made on the velocity of combustion of powder under pressures equal to or less than one atmosphere. But the extent of these experiments is too limited in order to take from them useful data for interior ballistics. In a remarkable *Étude sur les poudres du nouveau matériel de l'artillerie de terre,** M. Castan shows some facts of experiment for pressures greater than one atmosphere, and remarks that the influence of the pressures on the combustion of powder is made manifest by the examination of firings under the same conditions.

If we admit that the charge of a gun is completely burned when the projectile leaves the bore, one ought to conclude, from the time taken by the projectile to move through the bore, that the period of combustion of powder is much less than that observed in free air. M. Castan estimates, for example, that a powder of which the velocity of combustion is 10 millimetres a second in free air, should burn with a mean velocity of 320 millimetres under the variable pressure produced in large-calibred guns for naval use.†

* Revue d'artillerie, Vol. 1, p. 105.

† It is often useful to have the *mean pressure* produced in a gun, that is to say, the *constant* pressure necessary to produce an observed initial velocity. It is calculated as follows:

Let v = the initial velocity,

m = the mass of the projectile,

u = the space passed over by the projectile in the bore.

The constant force corresponding to the velocity v is evidently $\frac{1}{2} \cdot \frac{mv^2}{u}$; dividing by the area of a right section of the bore ω, we have for the mean pressure

$$P_m = \frac{1}{2} \cdot \frac{mv^2}{\omega u}.$$

36. We have no accurate data on the form of the relation which connects the velocity of combustion of powder with the exterior pressure. In the course of these researches we suppose that the velocity of combustion is proportional to a positive power of the pressure.

According to this hypothesis, which is besides the most simple that one can make in order to represent analytically a function increasing with the variable and vanishing with it, if we designate by:

v_0 the velocity of combustion under the normal atmospheric pressure p_0,

v the velocity under the pressure p,

a a positive number;

we have:

(38) $$v = v_0 \left(\frac{p}{p_0}\right)^a.$$

The experiments made up to this date (1877) are not sufficient to determine a with precision. In the meantime we can conclude with certainty that the velocity increases less rapidly than the pressure, that is to say, that a is less than unity.

The following considerations, which, however, we do not state as exact, lead to the value $a = \frac{1}{2}$.

37. The movement of the inflaming gases penetrating into the interior of the substance of the powder can be considered as placed under the action of two opposing forces, which are the exterior pressure p, and the resistance of the material, which, arising from the movement of the gases, is a function $f(v)$ of their velocity.

These two forces are in equilibrium, since the movement of the gases is uniform under constant pressure, and we have the relation,

$$p = f(v).$$

This being granted, the resistance $f(v)$, reduced to the unit of mass of the gases, is probably proportional:

1st. To the velocity v, that is to say, to the number of particles of the resisting medium which are opposed in the unit of time to the movement of the gases.

2d. To a certain function of the velocity vanishing for $v = 0$, and proportionally representing the resistance due to each particle of the medium.

In admitting that this last function should be proportional to the velocity, the function $f(v)$ would be proportional to the square of the velocity, and it follows from the relation $p = f(v)$, the velocity would be *proportional to the square root of the pressure.*

38. Before examining the effect of the pressure on the laws of the combustion of powder, it is well to recall briefly the divers forms which one should attribute to the function $\psi(t)$ when the combustion takes place under constant pressure. This function is generally developed according to integral powers of the variable, and in our first researches we have supposed it reduced to the form

$$\psi(t) = at(1 + \lambda t + \mu t^2 + \ldots),$$

$a, \lambda, \mu \ldots$ being coefficients depending on the form and dimensions of the grain.

In the researches which follow we will modify à little this notation, by putting

$$\psi(t) = \frac{at}{\tau}\left(1 - \lambda\frac{t}{\tau} + \mu\frac{t^2}{\tau^2} + \ldots\right), \tag{39}$$

τ being the period of the combustion of the grain, and $a, \lambda, \mu, \ldots$ (*), coefficients which, in consequence of the new form adopted, are purely *numerical,* and retain the same value when the grain varies or remains similar to itself, the period of time τ being alone modified according to the ratio of similitude. We give hereafter the values of these coefficients for various forms of grains.

39. 1st. *Spherical grains.*—When the grain is spherical, designating by r its radius and by v the velocity of combustion, we have the well-known formula,

$$\psi(t) = 1 - \left(1 - \frac{vt}{r}\right)^3,$$

or better, observing that $r = v\tau$:

$$\psi(t) = \frac{3t}{\tau} - \frac{3t^2}{\tau^2} + \frac{t^3}{\tau^3}.$$

Consequently in this case:

$$a = 3,\ \lambda = 1,\ \mu = \tfrac{1}{3}. \tag{40}$$

40. 2d. *Pierced cylindrical grains.*—This form is not used; the corresponding formula however presents a theoretical interest, because it offers a simplified representation of the law according to which the combustion of pierced prismatic grains operates, these being the forms for some time used in guns of large calibre.

* We write $-\lambda$ in place of λ in the second term of ψ, because this term is negative for the various forms of grains used in practice (No. 39 *et seq.*)

Supposing the grain to be a cylinder of height h and radius r, pierced through its axis by a cylindrical hole of radius r', we have without difficulty the formula

$$\psi(t) = 2v\left(\frac{1}{h} + \frac{1}{r - r'}\right)t - \frac{4v^2}{h(r-r')}t^2.$$

The period of combustion is evidently obtained by dividing by v the half of the smaller of the dimensions h and $r - r'$. Denoting by x the ratio of the smaller to the greater of these dimensions we can write:

$$\psi(t) = (1 + x)\frac{t}{\tau} - x\frac{t^2}{\tau^2}.$$

From this expression we have the values

$$(41) \qquad a = 1 + x, \quad \lambda = \frac{x}{1 + x}, \quad \mu = 0.$$

41. 3d. *Grains of the form of a parallelopipedon.*—A very ingenious theory of Captain Castan has recently (1877) called attention to the special properties which may result from the use of grains having very nearly the form of a right parallelopipedon of rectangular base.

Designating by α, β, γ, the dimensions of a grain, the law of its combustion under constant pressure is represented by the formula:

$$\psi(t) = 1 - \left(1 - \frac{2vt}{\alpha}\right)\left(1 - \frac{2vt}{\beta}\right)\left(1 - \frac{2vt}{\gamma}\right),$$

or better, by developing:

$$\psi(t) = 2v\left(\frac{1}{\alpha} + \frac{1}{\beta} + \frac{1}{\gamma}\right)t - 4v^2\left(\frac{1}{\beta\gamma} + \frac{1}{\gamma\alpha} + \frac{1}{\alpha\beta}\right)t^2 + 8v^3\frac{1}{\alpha\beta\gamma}t^3.$$

Letting α be the least of the three dimensions, and x, y the ratios of α to β, γ, the period τ of the combustion is evidently determined by the relation $\tau = \frac{\alpha}{2v}$, and the expression above can be written:

$$\psi(t) = (1 + x + y)\frac{t}{\tau} - (x + y + xy)\frac{t^2}{\tau^2} + xy\frac{t^3}{\tau^3},$$

and we have consequently:

$$(42) \qquad a = 1 + x + y, \quad \lambda = \frac{x + y + xy}{1 + x + y}, \quad \mu = \frac{xy}{1 + x + y}.$$

When the grain is cubical, these values reduce to the values (40) or those of a spherical grain.

42. *Combustion under variable pressure.*—Suppose now a grain of powder to burn under variable pressure. The flame attaining at the

same time every point of its surface, is propagated by parallel surfaces with a variable velocity v; consequently the distance which separates, at any instant t, the surface in ignition and the initial surface is $\int_0^t vdt$ in place of vt as in the case of constant pressure. We have, for example, a spherical grain radius r. The initial volume is $\frac{4}{3}\pi r^3$; at any given instant t the radius has become $r - \int_0^t vdt$, and consequently the volume of powder burned is:

$$\frac{4}{3}\pi r^3 - \frac{4}{3}\pi\left(r - \int_0^t vdt\right)^3;$$

the function $\psi(t)$, the ratio of the actual volume to the initial volume, is then:

$$\psi(t) = 1 - \left(1 - \frac{1}{r}\int_0^t vdt\right)^3.$$

If we admit between the pressure and the velocity of combustion the relation (38), it becomes:

$$\psi(t) = 1 - \left[1 - \frac{v_0}{r}\int_0^t \left(\frac{p}{p_0}\right)^\alpha dt\right]^3,$$

since $\frac{v_0}{r}$ is the period of combustion under the *normal pressure* p_0; supposing then that τ denotes this particular period, the formula above can be written:

$$\psi(t) = 1 - \left[1 - \frac{1}{\tau}\int_0^t \left(\frac{p}{p_0}\right)^\alpha dt\right]^3.$$

It differs only from that relating to the combustion under constant pressure by the substitution of the integral $\int_0^t \left(\frac{p}{p_0}\right)^\alpha dt$ for t.

This result is general and may be extended to other forms of grains. If then the combustion of a grain under the normal pressure p_0 is represented by the function (39), the combustion of the same grain under variable pressure is represented by the formula:

$$(43) \qquad \psi(t) = \frac{a}{\tau}\int_0^t \left(\frac{p}{p_0}\right)^\alpha dt\left[1 - \frac{\lambda}{\tau}\int_0^t \left(\frac{p}{p_0}\right)^\alpha dt + \ldots\right],$$

and the law of the combustion of a weight ϖ of powder formed of equal grains and ignited simultaneously will be: $y = \varpi\psi(t)$.

43. We apply formula (43) to the combustion of the charge in the interior of the gun.

The force applied to the projectile is $m\frac{d^2u}{dt^2}$; dividing by the area of a right section of the bore, we have the pressure for a unit of surface as follows:

$$p = \frac{m}{\omega}\cdot\frac{d^2u}{dt^2}.$$

Substituting in (43), we have for the weight y of the powder burned in the time t:

$$(44)\quad y=\frac{a\varpi}{\tau}\left(\frac{m}{\omega p_0}\right)^{\alpha}\int_0^t\left(\frac{d^2u}{dt^2}\right)^{\alpha}dt\left[1-\frac{\lambda}{\tau}\left(\frac{m}{\omega p_0}\right)^{\alpha}\int_0^t\left(\frac{d^2u}{dt^2}\right)^{\alpha}dt+\ldots\right].$$

Putting this value in (17) we have the definite equation of the movement of the projectile. We examine in the following chapter the properties and general laws derived from it.

44. *Calculation of the period of combustion.*—In order to calculate the value of τ which enters into these formulæ, it is necessary to know

1st. The velocity of combustion under the atmospheric pressure.

2d. The least dimension of the grain.

The first of these elements has been determined experimentally by Piobert for powders of different composition and fabrication. The result of his experiments is that, all other things being equal, the velocity of combustion of a powder *varies inversely with its density.* We have, therefore,

$$(45)\qquad v_0=\frac{c}{\delta},$$

δ being the density of the grain, and c a constant depending upon the composition and degree of dryness of the material. It depends also upon the process of fabrication and on the period or duration of trituration, but the variations resulting would seem to be relatively small. We can with a sufficiently general approximation suppose that, within the limits of dryness realized in the habitual conditions of fabrication, the value of c to be nearly:

0.200 for powders for war purposes and for English powders;

0.130 for sporting powder (the units being the decimeter and the second).

45. With regard to the least dimension of the grain, it is deduced, generally *from the density* and from the *number of grains in a kilogram.*

1st. *Spherical grains.*—Let a spherical grain have a radius r and density δ, and N be the number of grains to the kilogram. The weight of a grain is $\frac{4}{3}\pi r^3\delta$, and we have: $\frac{4}{3}\pi r^3\delta N=1$, whence

$$(46)\qquad r=\left(\frac{3}{4\pi\delta N}\right)^{\frac{1}{3}}.$$

This form of grain is rarely used in practice, but when the form and the dimensions of the grains of a charge are *very irregular*, the

grain can be assimilated to a *mean* sphere, the radius of which will be given by formula (46).

2d. *Grains of the form of a parallelopipedon.*—Suppose now a grain the form of a parallelopipedon, and let α, β, γ, be the three dimensions, α being the smallest. Put as in No. 41 $\frac{\alpha}{\beta}=x$, $\frac{\alpha}{\gamma}=y$. We have evidently:

$$\alpha\beta\gamma\delta N=\frac{\alpha^3}{xy}\delta N=1,$$

whence

$$\alpha=\left(\frac{xy}{\delta N}\right)^{\frac{1}{3}}, \tag{47}$$

and when the grain is cubical:

$$\alpha=\left(\frac{1}{\delta N}\right)^{\frac{1}{3}}. \tag{48}$$

These elements being calculated, we have the duration of combustion by the formula $\tau=\frac{r}{v}$, when the grain is spherical or irregular; and by the formula $\tau=\frac{\alpha}{2v}$, when the grain is cubical or of the form of a parallelopipedon.

CHAPTER IV.

General Law and Properties of the Motion of a Projectile in the Bore.

46. We have established in the preceding chapters the general form of the equation which gives the motion of a projectile in the bore. This equation is as follows:

$$(u+z)\frac{d^2u}{dt^2}+\theta\left(\frac{du}{dt}\right)^2=\frac{f\alpha\varpi}{m\tau}\left(\frac{m}{\omega p_0}\right)^{\alpha}\int_0^t\left(\frac{d^2u}{dt^2}\right)^{\alpha}dt \tag{49}$$
$$\times\left\{\begin{array}{l}1-\frac{\lambda}{\tau}\left(\frac{m}{\omega p_0}\right)^{\alpha}\int_0^t\left(\frac{d^2u}{dt^2}\right)^{\alpha}dt+\\ \frac{\mu}{\tau^2}\left(\frac{m}{\omega p_0}\right)^{2\alpha}\left[\int_0^t\left(\frac{d^2u}{dt^2}\right)^{\alpha}dt\right]^2\\ +\dots\dots\dots\dots\dots\dots\end{array}\right.$$

where

u is the displacement of the projectile,

m its mass;

ϖ the weight of the charge of powder;

ω the right section of the bore;
f the force of the powder;
τ the time of burning of a grain under the normal atmospheric pressure p_0;
$\alpha, \gamma, \mu, \ldots$ numerical coefficients depending upon the form of the grain;
z the reduced length of the initial air space, calculated by (18) or (19);
a the exponent of the power to which we have supposed the velocity of combustion of the powder proportional;
θ the numerical coefficient defined by No. 20.

The problem of the motion of a projectile in a gun is then reduced to finding a function u of t which will satisfy (49), and vanish, with its first derivative $\frac{du}{dt}$, when $t=0$. The numerical determination of this function may be effected by the ordinary methods of approximation used in the integration of differential equations; it requires that the numerical coefficients a and θ shall be known. We shall return to this in the succeeding chapter. But, without this determination, we may deduce from the form of this equation certain general properties of the function u which, from a practical view, appear worthy of remark.

47. Equation (49) depends upon the variables enumerated in the preceding number, and changes with the dimensions of the piece used and the manner of loading. We shall first show that we may substitute for it a system of *purely numerical* equations, and common, therefore, to all cases.

Let y equal the ratio of u to the reduced length of the initial air-space, so that

$$u = yz, \tag{50}$$

and put, for shortness,

$$K = \frac{f\alpha\varpi}{mz^2\tau}\left(\frac{mz}{\omega p^0}\right)^a, \tag{51}$$

$$Y = \int_0^t \left(\frac{d^2y}{dt^2}\right)^a dt; \tag{52}$$

equation (49) then becomes

$$(y+1)\frac{d^2y}{dt^2} + \theta\left(\frac{dy}{dt}\right)^2 = KY\left[1 - \frac{\lambda}{\tau}\left(\frac{mz}{\omega p_0}\right)^a Y + \frac{\mu}{\tau^2}\left(\frac{mz}{\omega p_0}\right)^{2a} Y^2 + \ldots\right]. \tag{53}$$

Change the independent variable t to x, defined by the relation

$$x = K^\beta t, \tag{54}$$

K being the quantity defined by (51), and β an undetermined exponent. We have

(55) $$\frac{dy}{dt} = K^{\beta}\frac{dy}{dx}, \quad \frac{d^2y}{dt^2} = K^{2\beta}\frac{d^2y}{dx^2}.$$

We have also $dt = K^{-\beta}.dx$. From this, and the value of $\frac{d^2y}{dx^2}$ in (55), (52) becomes

(56) $$Y = K^{(2\alpha-1)\beta}\int_0^x\left(\frac{d^2y}{dx^2}\right)^{\alpha}.dx$$

or

(57) $$Y = K^{(2\alpha-1)\beta}X,$$

if we write

(58) $$X = \int_0^x\left(\frac{d^2y}{dx^2}\right)^{\alpha}.dx.$$

Substituting the values from (55) and (57) in (53), and putting,

(59) $$\gamma = 1 + (2\alpha - 3)\beta, \quad \varepsilon = \left(\frac{mz}{\omega p_0}\right)^{\alpha}K^{(2\alpha-1)\beta},$$

we find,

(60) $$(y+1)\frac{d^2y}{dx^2} + \theta\left(\frac{dy}{dx}\right)^2 = K^{\gamma}X(1 - \lambda\varepsilon X + \mu\varepsilon^2X^2 + \ldots)$$

Determining β so as to make γ vanish, which, by (59) gives

(61) $$\beta = \frac{1}{3 - 2\alpha},$$

(62) $$\varepsilon = \frac{1}{\tau}\left(\frac{mz}{\omega p_0}\right)^{\alpha}K^{\frac{2\alpha-1}{3-2\alpha}},$$

equation (60) is finally reduced to the following,

(63) $$(y+1)\frac{d^2y}{dx^2} + \theta\left(\frac{dy}{dx}\right)^2 = X - \lambda\varepsilon X^2 + \mu\varepsilon^2X^3 + \ldots$$

48. To satisfy this equation, suppose the unknown function y developed in a series of ascending powers of ε, in the form

(64) $$y = y_0 + \varepsilon y_1 + \varepsilon^2 y_2 + \ldots,$$

$y_0, y_1, y_2, \ldots$ being unknown functions of x. We have then

$$\frac{d^2y}{dx^2} = \frac{d^2y_0}{dx^2}\left[1 + \varepsilon\frac{d^2y_1}{dx^2}\left(\frac{d^2y_0}{dx^2}\right)^{-1} + \varepsilon^2\frac{d^2y_2}{dx^2}\left(\frac{d^2y_0}{dx^2}\right)^{-1} + \ldots\right]$$

Developing $\left(\frac{d^2y}{dx^2}\right)^{\alpha}$ by the binomial theorem, and putting,

$$
(65)\quad \begin{cases}
X_0 = \int_0^x \left(\frac{d^2y_0}{dx^2}\right)^a . dx, \\
X_1 = a\int_0^x \frac{d^2y_1}{dx^2}\left(\frac{d^2y_0}{dx^2}\right)^{a-1} . dx, \\
X_2 = a\int_0^x \frac{d^2y_2}{dx^2}\left(\frac{d^2y_0}{dx^2}\right)^{a-1} . dx \\
\qquad + \frac{a(a-1)}{1.2}\int_0^x \left(\frac{d^2y_1}{dx^2}\right)^2\left(\frac{d^2y_0}{dx^2}\right)^{a-2} . dx \\
\dots\dots\dots\dots\dots\dots
\end{cases}
$$

we easily find for (58),

$$
(66)\qquad X = X_0 + \varepsilon X_1 + \varepsilon^2 X_2 + \dots
$$

Substituting the values of y, $\frac{dy}{dx}$, $\frac{d^2y}{dx^2}$, X, in (63), and equating the coefficients of like powers of ε, we have the following system of equations,

$$
(67)\quad \begin{cases}
(y_0 + 1)\frac{d^2y_0}{dx^2} + \theta\left(\frac{dy_0}{dx}\right)^2 = X_0, \\
(y_0 + 1)\frac{d^2y_1}{dx^2} + 2\theta\frac{dy_0}{dx}\cdot\frac{dy_1}{dx} + \frac{d^2y_0}{dx^2}y_1 = X_1 - \lambda X_0^2, \\
\left.\begin{aligned} &(y_0 + 1)\frac{d^2y_2}{dx^2} + 2\theta\frac{dy_0}{dx}\cdot\frac{dy_2}{dx} \\ &\quad + \frac{d^2y_0}{dx^2}y_2 + y_1\frac{d^2y_1}{dx^2} + \theta\left(\frac{dy_1}{dx}\right)^2 \end{aligned}\right\} = X_2 - 2\lambda X_0 X_1 + \mu X_2^2,
\end{cases}
$$

and it will fulfil all the conditions of the problem if we find a system of functions $y_0, y_1, y_2, \dots$, which will satisfy these equations, and vanish with their first derivatives when $x = 0$.

These equations are numerical, and remain the same whatever may be the conditions of fire, for the same system of values for λ, μ, ..., that is to say, for the same form of grain.

The functions which are determined by these equations may be tabulated, as in the case of logarithms, and the circular functions; and this labor performed, we can see that (64) furnishes the complete solution of the problem.

49. *General formulæ of initial velocities and pressures.*—The displacement of the projectile u being equal to zy, the velocity v, and acceleration w have the values, from (55)

$$
v = zK^\beta \frac{dy}{dx}, \quad w = zK^{2\beta}\frac{d^2y}{dx^2}.
$$

To deduce the pressure p on unit surface, we have only to multiply w by m, and divide by ω. If we replace y by its value (64), we have the two formulæ

(68) $$v = zK^{\beta}\left(\frac{dy_0}{dx} + \varepsilon\frac{dy_1}{dx} + \varepsilon^2\frac{dy_2}{dx} + \ldots\right),$$

(69) $$p = \frac{mz}{\omega}K^{2\beta}\left(\frac{d^2y_0}{dx^2} + \varepsilon\frac{d^2y_1}{dx^2} + \varepsilon^2\frac{d^2y_2}{dx^2} + \ldots\right).$$

The coefficients of the second member are numerical coefficients of $x = K^{\beta}t$. These formulæ express then the velocity and pressure as a function of the time. To express them as a function of the distance passed over, we have only to suppose that we have taken from (64) the value of x as a function of y in the form,

(70) $$x = x_0 + \varepsilon x_1 + \varepsilon^2 x_2 + \ldots$$

and substituted this value in (68) and (69), whose coefficients then become functions of $y = \frac{u}{z}$. We have thus

(71) $$v = zK^{\beta}\left[F_0\left(\frac{u}{z}\right) + \varepsilon F_1\left(\frac{u}{z}\right) + \varepsilon^2 F_2\left(\frac{u}{z}\right) + \ldots\right],$$

(72) $$p = \frac{mz}{\omega}K^{2\beta}\left[f_0\left(\frac{u}{z}\right) + \varepsilon f_1\left(\frac{u}{z}\right) + \varepsilon^2 f_2\left(\frac{u}{z}\right) + \ldots\right],$$

which show the forms of the relations which must connect v and p with the various elements of fire. The functions F and f are numerical; the quantities K, ε, β, have the values given in (51), (62), (61).

By giving to u a value equal to the initial distance of the base of the projectile from the muzzle, (71) evidently becomes a formula for initial velocity.

50. *Similar guns.*—Two guns are *similar* when all their homologous linear dimensions are proportional to their calibres. The reduced length of the chamber being then proportional to the calibre, the quantity z, which is itself proportional to the former, varies in the same ratio; the cross section of the bore ω is proportional to the square of the calibre.

The similitude is extended to the loading when the weights of the powder and the projectile are proportional to the cube of the calibre, and when the grains of powder have the same form and dimensions proportional to the calibre. Consequently, the coefficients a, λ, μ, . . . must have the same value, and the time of combustion τ must vary, between the two guns, proportionally to the calibre.

When these conditions are fulfilled the relations (51) and (62) show that K^β varies in inverse ratio of the calibre, and that ε is constant. It results, therefore, from (71) and (72) that the values of v and p are equal for equal values of $\frac{u}{z}$, that is, for values of u proportional to the calibre.

This principle follows:

In similar guns, similarly loaded, the velocities and pressures corresponding to distances passed over proportional to the calibres, are equal.

This principle requires that the duration of combustion shall be proportional to the calibre; it ceases to be applicable if, all other circumstances of similitude being observed, the powder is the *same* in the two guns. The equality of the velocities and pressures then no longer exists, contrary to the opinion which is very generally held. Consequently, the empirical formulæ, established upon the hypothesis of this equality, are not exact; we shall see further on that the error committed by their use, even in guns which are nearly alike, may be quite large.

51. The principle of the similitude of guns being of great importance in practical applications, it has been thought better to deduce them from the fundamental formulæ in their most general form. In the researches which follow, we shall simplify the formulæ by limiting the number of terms considered. The quantity ε being generally quite small, we may admit that the series (71) and (72) are very convergent, and that the first two terms give a sufficient approximation, similarly to what we have already stated in our first researches, in deriving the expression which gives the initial velocity when the effect of the variation of pressure upon the combustion of the powder is neglected.

The formulæ are thus greatly simplified, and we may, moreover, introduce, in explicit form, the coefficient λ, which, as well as a, depends upon the form of the grain.

52. Consider the development (64) which expresses the displacement of the projectile as a function of the time. The first term, y_0, is defined by the first of (67); which, as has already been remarked, is purely numerical, and does not depend on either λ or μ . . . The coefficient y_1 of the second term satisfies the second of (67). Replacing X_1 in this equation by its value in (65), we easily see that all the terms containing the unknown quantity are *linear*. Moreover, the term

which is independent of the unknown quantity, being proportional to λ, it is clear that y_1 is the product of λ by a numerical function of x.

The second term of (64), and consequently the second term of (70), are then proportional to λ. We have the same results also evidently for the developments (71) and (72), whose second terms are equal to the product of λ by functions of $\frac{u}{z}$.

These functions are, moreover, positive. In fact, if the combustion of a grain under constant pressure were uniform, the coefficients $\lambda, \mu, \ldots$, would vanish; and the series (71) and (72) would be reduced rigidly to their first terms. But the combustion is not uniform in possible shapes of grain; on account of the progressive diminution of the surfaces of emission, the gas is formed with a decreasing velocity; this causes a diminution of the initial velocity and of the rate of increase of pressure in the space passed over. We may then put,

$$F_1\left(\frac{u}{z}\right) = -\lambda\varphi_1\left(\frac{u}{z}\right), \quad f_1\left(\frac{u}{z}\right) = -\lambda\psi_1\left(\frac{u}{z}\right),$$

φ_1, ψ_1 being increasing functions of $\frac{u}{z}$. If, to make the notation symmetrical, we write φ_0 and ψ_0 in place of F_0 and f_0, formulæ (71) and (72), reduced to their first terms, become,

$$(73) \qquad v = zK^\beta\left[\varphi_0\left(\frac{u}{z}\right) - \varepsilon\lambda\varphi_1\left(\frac{u}{z}\right)\right],$$

$$(74) \qquad p = \frac{mz}{\omega}K^{2\beta}\left[\psi_0\left(\frac{u}{z}\right) - \varepsilon\lambda\psi_1\left(\frac{u}{z}\right)\right],$$

whence we derive several important consequences.

53. *Formula of pressures.*—Consider first (74), which gives the pressure.

The maximum pressure, which is what endangers the gun, is generally when the shot has moved a small distance only; the value of p may at that point be reduced to that of its first term. We have then

$$(75) \qquad p = \frac{mz}{\omega}K^{2\beta}\psi\left(\frac{u}{z}\right).$$

The function ψ is purely numerical, and entirely independent of the elements of fire. Let b be the value of the variable which corresponds with the maximum, and let A be the value of the maximum. The maximum pressure in the bore is then,

$$(76) \qquad P = A\frac{mz}{\omega}K^{2\beta},$$

or, recollecting the values of K and β in (51) and (61),

(77) $$P = A\frac{mz}{\omega}\left(\frac{fa\varpi}{\tau mz^2}\right)^{\frac{2}{3-2a}}\left(\frac{mz}{\omega p_0}\right)^{\frac{2a}{3-2a}}.$$

Expressed in atmospheres, the pressure is

(78) $$\frac{P}{p_0} = A\left(\frac{mz}{\omega p_0}\right)^{\frac{3}{3-2a}}\left(\frac{fa\varpi}{\tau mz^2}\right)^{\frac{2}{3-2a}}.$$

54. We have called b the value of the variable for which $\psi\left(\frac{u}{z}\right)$ is a maximum. The corresponding value of the displacement is

$$u = bz.$$

We therefore see that, in the degree of approximation adopted, the displacement of the projectile corresponding to the maximum pressure is proportional to the *reduced length of the initial air space.* The only elements of fire upon which its value depends are then, by (18), the reduced length of the chamber, the density of loading, and the density of the powder.

This depends upon the supposition that the expression for the pressure is reduced to its first term. It ceases to be the case if the second term may not be neglected. This may become the case from the use of rapidly burning powders; the value of ε (62) increases as τ decreases.

The value of $y = \frac{u}{z}$, corresponding to the maximum of p, may be obtained by putting the first derivative of $\psi_0(y) - \varepsilon\lambda\psi_1(y)$ equal to zero. We thus have,

(79) $$\psi'_0(y) - \varepsilon\,\psi'_1(y) = 0.$$

Let $b + \delta b$ be the root we wish to find; we have then

$$\psi'_0(b + \delta b) - \varepsilon\lambda\psi'_1(b + \delta b) = 0.$$

Considering δb a quantity of the first order, noting that $\psi'(b) = 0$, and neglecting the quantities of the second order, we have,

(80) $$\delta b = \varepsilon\lambda\frac{\psi'_1(b)}{\psi'_0(b)};$$

$\psi''_0(b)$ is negative because $\psi_0(b)$ is a maximum, $\psi'_1(b)$ is positive because ψ_1 is an increasing function; therefore δb is negative. Consequently the displacement corresponding to the maximum pressure is less than bz, which is therefore a superior limit.

The maximum pressure is a little less than that given by (76). In fact, for the value $b+\delta b$ of the variable, the function $\psi_0(y)-\varepsilon\lambda\psi_1(y)$ is reduced, by neglecting the small quantities of the second order, to

$$\psi_0(b)-\varepsilon\lambda\psi_1(b).$$

This value is less than $\psi_0(b)=A$. In fact, the influence of the second term seems generally small, and (76) and (77) give the pressure with a sufficient approximation for practical purposes, as we shall see later.

55. *Formula for velocity.*—On the contrary, the two first terms must be retained for the initial velocity, which corresponds nearly always to a value of $\frac{u}{z}$ decidedly larger than the one corresponding to the maximum pressure. Upon the ratio between these two terms depends the influence of the form of grain upon the relative values of the velocities and pressures. We shall treat this matter more at length. The formula for velocity, reduced to two terms, when K and ε are replaced by their values, becomes

$$(81)\qquad v=z\left(\frac{fa\varpi}{\tau mz^2}\right)^{\frac{1}{3-2a}}\left(\frac{mz}{\omega p_0}\right)^{\frac{a}{3-2a}}\left[\varphi_0\left(\frac{u}{z}\right)\right.$$
$$\left.-\frac{\lambda}{\tau}\left(\frac{fa\varpi}{\tau mz^2}\right)^{\frac{2a-1}{3-2a}}\left(\frac{mz}{\omega p_0}\right)^{\frac{2a}{3-2a}}\varphi_1\left(\frac{u}{z}\right)\right].$$

This is somewhat complicated; and it will be simplified greatly by taking (see No. 37) $a=\frac{1}{2}$. For the moment, however, we shall leave it in its general form, in order to deduce some consequences without putting any unnecessary restrictions upon it.

56. *Influence of the nature of the powder upon its effects.*

1st. *Pressures.*—All other elements being the same, the maximum pressure depends upon the nature of the powder; by (77) this element enters in the quantity $\frac{fa}{\tau}$; which depends upon the three variables f, a, and τ.

f is the force of the powder. If we suppose it given by (2), it is evident that it is proportional to the *temperature of combustion of the powder*, and to the *volume of permanent gas* generated. We may then consider that its value depends principally upon the composition of the powder used.

a is a *number* which depends only on the form of the grain. Its value has been given in No. 39, and the following numbers for the ordinary powders.

τ is the time of combustion of a grain of powder under normal atmospheric pressure. It may be found by dividing the least dimension of the grain by the velocity of combustion; the latter varies, as is known, according to the manner of fabrication.

It results then that if these three elements vary in such a way as to keep $\frac{fa}{\tau}$ constant, the maximum pressure will be constant.

57. 2d. *Initial velocities.*—Equation (81) shows that the initial velocity depends not only upon $\frac{fa}{\tau}$, but also upon $\frac{\lambda}{\tau}$, λ being a second *number* which, like a, is characteristic of the form of the grain.

We see also that the formula for velocity consists of two terms. The first alone would remain in the ideal case where the form of the grain was such as to make the combustion *uniform* under constant pressure. The second term, proportional to $\frac{\lambda}{\tau}$, is subtractive, and represents the effect of the decrease of the velocity of emission which is caused in all possible forms of grain.

It is evidently advantageous to make this term as small as possible, and our formulæ show clearly that, if several powders produce the same maximum pressure under the same conditions of fire, that for which the quantity $\frac{\lambda}{\tau}$ is least gives the greatest velocity.

58. Consider, for example, two powders having the characteristic elements,

$$f\,,\ \tau\,,\ a\,,\ \lambda\,.$$
$$f',\ \tau',\ a',\ \lambda'.$$

If we suppose that

$$\frac{fa}{\tau} = \frac{f'a'}{\tau'}, \tag{82}$$

the maximum pressure is the same and the ratio of the subtractive terms is $\frac{\lambda'\tau}{\lambda\tau'}$. If this ratio is < 1, the second powder will give a greater velocity with the same pressure.

59. *Influence of the force of the powder.*—Suppose that the form of the grain is the same for two powders, so that $a' = a$, $\lambda' = \lambda$. The equality of pressures is realized if

$$\frac{f}{\tau} = \frac{f'}{\tau'},$$

and the ratio of the two subtractive terms is then $\frac{f}{f'}$. Consequently, the strongest powder gives the same maximum pressure and a greater velocity.

It seems impossible to vary the force of powders of the nitrate of potassium class of powders by varying the proportions. When they are varied, the heat of combustion and the volume of gas vary considerably; but experiment shows that the product of these two quantities, which is an approximate measure of the force, varies very little.

We obtain much more force by using the picrates; which, with equal weights, evolve more heat and more gas than ordinary powder.

This essential condition was probably not realized in certain circumstances in which picric powder was observed to exert a dangerous energy. The foregoing considerations indicate that they may be less destructive than ordinary powder, since, as they can give a greater velocity with the same pressure, they can probably give a lower pressure with the same velocity.

60. *Influence of the form and dimensions of the grain.*—Consider, secondly, two powders which are equally strong; but which differ in the form and dimensions of the grain. Putting $f = f'$, the condition of equality of pressures becomes

$$\frac{a}{\tau} = \frac{a'}{\tau'},$$

and the ratio of the subtractive terms of the velocity is

$$\frac{\lambda' a}{\lambda a'}. \tag{83}$$

For the spherical or cubical grain, we have (Nos. 39 and 41),

$$a = 3, \quad \lambda = 1.$$

Let us compare this grain with other possible forms.

1st. *Cylindrical pierced grain.*—This grain has two dimensions: height and thickness. Calling x the ratio of the least to the greatest, we have (No. 40),

$$a' = 1 + x, \quad \lambda' = \frac{x}{1 + x}.$$

The ratio (83) has then the value

$$\frac{3x}{(1 + x)^2}. \tag{84}$$

This function of x is a *maximum* for $x = 1$; its value then being $\frac{3}{4}$. Consequently, by using *cylindrical pierced grains of equal height*

and thickness, the subtractive term corresponding to spherical or cubical grains may be diminished by *one-fourth* of its value. If its absolute value is 100 meters, for example, we would gain 25 meters of velocity without increase of maximum pressure. The gain increases for decreasing values of x; if we take $x = \frac{1}{2}$, the subtractive term is diminished by *one-third*; and, supposing the same absolute value of the velocity, the increase is about 33 meters.

2d. *Grains of the form of a parallelopiped.*—Calling x and y the ratio of the least side to the two others, we have (No. 42),

$$a = 1 + x + y, \quad \lambda = \frac{x + y + xy}{1 + x + y}, \tag{85}$$

and the ratio of the subtractive term to that for the spherical or cubical grain is

$$\frac{3(x + y + xy)}{(1 + x + y)^2}. \tag{86}$$

If the grain has a square base, we have $y = x$; and the above ratio becomes

$$\frac{3(2x + x^2)}{(1 + 2x)^2}. \tag{87}$$

This expression diminishes as x varies from 1 to 0, but the change is somewhat slow. When two dimensions of the grain are double the third, $x = \frac{1}{2}$, and the value of the ratio is $\frac{15}{16}$. The velocity therefore increases by $\frac{1}{16}$ of the subtractive term corresponding to the spherical grain. Supposing this term 100 meters, it is about 7; it becomes 16 for $x = \frac{1}{3}$.

The advantage of flattened grains over those which are spherical or cubical seems then real; but the advantage appears to be less than in the case of grains which are pierced.

61. *Theoretical force of some powders.*—The numerical application of the preceding theories requires that the *velocity of combustion* and *force* of the powder shall be known.

The velocity of combustion must be observed under the normal atmospheric pressure, .760m. It has been determined for a great many powders by Piobert, and the figures he has given may still give a sufficient approximation in many cases. In No. 45, some experimental results, which will give at least an approximate value of this element in the ordinary conditions of practice, are given.

The processes of fabrication having, however, been greatly altered since the time of Piobert, it has seemed advisable to undertake new experiments with the new powders.

The *force* of the powder is the element whose direct determination offers the greatest difficulties ; there is no experiment which gives its value with certainty for any powder.

In the want of more precise data, we present the *theoretical* values which we derived with M. Roux from the experimental determinations made at the Dépôt Centrale des Poudres et Salpêtres. These values were deduced, by (3) of the first chapter, from the temperatures of combustion and the volume of the permanent gas.

Kind of powder.	Proportions.			Temp. of combustion.	Volume of gas.	Force of the powder.
	Nitre.	Sulphur.	Charcoal.	T_0 degr.	v_0 liters.	f
Fine sporting powder,	78	10	12	4654	234	412000
Cannon powder,	75	12.5	12.5	4360	261	431000
Small-arm powder, called B,	74	10.5	15.5	4231	280	448000
Commercial powder,	72	13	15	4042	281	430000
Ordinary blasting powder,	62	20	18	3372	307	392000

The units taken are the kilogram and decimeter. Consequently, according to the definition of the force of a powder, the figures in the table express in kilograms the pressure per square decimeter of the permanent gases of a kilogram of powder, occupying, at the temperature of combustion, the volume of one liter.

The figures of this table confirm what was said in No. 59 concerning the equality of the force of powders which have been differently made.

62. If according to No. 37, we take the velocity of combustion of powder to be proportional to the square root of the pressure, we put $\alpha = \frac{1}{2}$ in the preceding formulæ. We thus obtain new and very simple expressions which, as we shall see later, appear to represent accurately facts and the results of experiment.

63. *Formula for pressures, when* $\alpha = \frac{1}{2}$.—Replacing α by $\frac{1}{2}$, and z by its value in (19), equation (77), for the pressure, becomes,

$$P = A \frac{fa}{\tau\omega} \left[\frac{m\varpi\delta\Delta}{p_0(\delta - \Delta)} \right]^{\frac{1}{2}}, \tag{88}$$

where

f is the force of the powder,

τ the time of burning of a grain under the pressure p_0,

ω the right section of the bore,

m the mass of the projectile,

ϖ the weight of the powder,
Δ the density of loading,
δ the density of the powder,
a a numerical coefficient depending upon the form of grain,
A an absolute number whose value is independent of the elements of fire, and of the units chosen.

64. *Determination of A by experiment.*—To determine A theoretically, it would be necessary to integrate the first of (66), and deduce a table of values of the function φ_0, of which A is the maximum. This determination, which, however, will be effected later, is not necessary. The essential form of the function which gives the maximum pressure being fixed, we have only, to determine A, to measure the pressure in known conditions of fire—a single experiment is enough.

The following is an example of this determination by means of a navy gun of 24 centimeters; Wetteren powder was used (13 to 16 millimeters). The values of the various quantities on which the pressure depended were as follows (kilogram, decimeter and second being the units taken):

$$f = 431000^* \qquad a = 3^\dagger \qquad \tau = 0.6^\ddagger$$
$$m = \frac{144}{g}^\S, \qquad \varpi = 26, \qquad \Delta = .762,$$
$$\delta = 1.80, \qquad p_0 = 103.33 \qquad \omega = 4.60^\P$$

In these conditions, the mean of three *manomètres à écrasement* in the powder chamber gave 2300 kilos per square cm. We have, therefore, $P = 230000$; from which we have the value

$$A = 0.703.$$

It would be of interest to determine this coefficient by means of a more accurate instrument. This might be done by the use of the instrument lately invented by MM. Déprez and Sébert, and Captain Ricq.

65. *Pressures produced by the same powder in similar guns.*—In passing from one similar gun to another, m and ϖ vary as the cube of

* This value is the one which, in table in No. 62, belongs to cannon powder, whose elements are in the same proportion as in the Wetteren powder.

† The grain being irregular, it was assumed that the value of a for a sphere could be taken.

‡ This value is obtained by taking a velocity of combustion of 11.7 mm. per second, and calculating the mean radius of grain by (46), with the values $N = 350$, $\delta = 1.8$.

§ $g = 98.09$ d.

¶ The calibre is 2.42 d. c.

the calibre, and ω as its square; the density of loading Δ remains the same. If then the powder is the same for the two arms, τ does not change; and we see, from (88), that the maximum pressure varies proportionally to the calibre. Consequently, we may lay down the following law:

In similar guns, charged with the same powder, the maximum pressure is proportional to the calibre.

This law may often be made of use. For example: experiment has shown that the maximum pressure developed by Wetteren powder (13 to 16 mill. grains) in a 24 cm. gun is about 2300 kilos per square cm.; from which we conclude that the pressure of the same powder in a 14 cm. gun will be $2300 \times \frac{14}{24} = 1340$ kilos per square cm. about.

66. *Formula for velocities in the hypothesis,* $\alpha = \frac{1}{2}$.—Putting $\alpha = \frac{1}{2}$ in (81), we find;

$$(89) \qquad v = \left(\frac{f\alpha\varpi}{\tau m}\right)^{\frac{1}{2}} \left(\frac{mz}{\omega p_0}\right)^{\frac{1}{4}} \left[\varphi_0\left(\frac{u}{z}\right) - \frac{\lambda}{\tau}\left(\frac{mz}{\omega p_0}\right)^{\frac{1}{2}} \varphi_1\left(\frac{u}{z}\right)\right].$$

To apply this formula, the functions φ_0 and φ_1 must be known, or (67) must be integrated. But, without this, we may derive from (89) an *approximate* formula for initial velocities which may be useful.

67. *Approximate formula for initial velocity.*—The empirical formulæ by which initial velocities have been determined have generally been *monomial.* The form is much the simplest for calculation by logarithms, and it is not incompatible with the form which theory indicates, since any function may always, *within certain limits,* be considered as nearly proportional to a properly chosen power of the variable.

Adopting this method, we see that the quantity,

$$\varphi_0\left(\frac{u}{z}\right) - \frac{\lambda}{\tau}\left(\frac{mz}{\omega p_0}\right)^{\frac{1}{2}} \varphi_1\left(\frac{u}{z}\right),$$

which is an increasing function of $\frac{u}{z}$ and a decreasing one of $\frac{\lambda}{\tau}\left(\frac{mz}{\omega p_0}\right)^{\frac{1}{2}}$, may be considered, *as an approximation,* as proportional to a positive power γ' of the first of these variables, and to a negative power $-\gamma$ of the second. We may then, calling B a numerical factor, replace it by an expression of the form

$$B\left(\frac{\tau}{\lambda}\right)^{\gamma}\left(\frac{\omega p_0}{mz}\right)^{\frac{\gamma}{2}}\left(\frac{u}{z}\right)^{\gamma'}.$$

Consequently (89) becomes

$$v = B\left(\frac{fa\varpi}{\tau m}\right)^{\frac{1}{2}}\left(\frac{mz}{\omega p_0}\right)^{\frac{1-2\gamma}{4}}\left(\frac{\tau}{\lambda}\right)^{\gamma}\left(\frac{u}{z}\right)^{\gamma'}; \tag{90}$$

where γ and γ' may be determined by experiment. We shall return to this point in a special work.

Supposing that γ and γ' are known (90), enables us to evaluate numerically the influence of the various elements of fire upon the effects obtained. It exhibits, in particular, the proper influence of the characteristics of the powder used. This last, it appears, could hardly be obtained by any purely empirical method.

We shall now deduce from (90) some consequences which seem worthy of remark.

68. *Initial velocity attained by the same powder in similar guns.*—In similar guns, u and z vary with the calibre, ω as the square of the calibre, and m and ϖ as its cube. Also, a, τ and λ remain the same; we therefore conclude that *the initial velocity varies as the* $\frac{1-2\gamma}{2}$ *power of the calibre.*

69. *Initial velocities attained by different powders giving the same maximum pressure.*—Consider two powders having the characteristics,

$$f,\ \tau,\ a,\ \lambda,$$
$$f',\ \tau',\ a',\ \lambda'.$$

In the same conditions of fire these powders would give the same maximum pressure if their characteristics satisfy the relation (82),

$$\frac{fa}{\tau} = \frac{f'a'}{\tau'}.$$

This being fulfilled, formula (90) shows that the corresponding initial velocities are connected by the relation,

$$\frac{v'}{v} = \left(\frac{\lambda\tau'}{\lambda'\tau}\right)^{\gamma},$$

or, since

$$\frac{\tau'}{\tau} = \frac{f'a'}{fa},$$

$$\frac{v'}{v} = \left(\frac{f'a'\lambda}{fa\lambda'}\right)^{\gamma}. \tag{91}$$

We may thus compare various powders, and ascertain what influence the force of the powder and form of the grain exercise.

70. *Maxima pressures produced by different powders giving the same initial velocity.*—Consider, secondly, two powders which, in the

same conditions of fire, give the same initial velocity, and let us compare their pressures.

According to (90) the equality of velocities requires the condition

$$\left(\frac{fa}{\tau}\right)^{\frac{1}{2}}\left(\frac{\tau}{\lambda}\right)^{\gamma}=\left(\frac{f'a'}{\tau'}\right)^{\frac{1}{2}}\left(\frac{\tau'}{\lambda'}\right)^{\gamma},$$

whence

(92) $$\frac{\tau'}{\tau}=\left(\frac{fa}{f'a'}\right)^{\frac{1}{1-2\gamma}}\left(\frac{\lambda'}{\lambda}\right)^{\frac{2\gamma}{1-2\gamma}}.$$

Also, from (88)

$$\frac{P'}{P}=\frac{f'a'\tau'}{fa\tau};$$

consequently, recollecting (92), we have

(93) $$\frac{P'}{P}=\left(\frac{fa\lambda'}{f'a'\lambda}\right)^{\frac{2\gamma}{1-2\gamma}}.$$

71. *Approximate value of γ.*—In order that (91) and (93) shall be of any practical use, we must know the value of γ at least approximately.

Its value may be found from certain experimental data. Experiments made at Gavre with a 24 centimeter gun show that the initial velocities reached with projectiles of different mass, all other elements of fire being constant, vary inversely as the $\frac{4}{10}$ths power of the mass of the projectile.

Admitting this, it follows from (90) that we must have nearly

$$\frac{1-2\gamma}{4}=\frac{1}{10},$$

and consequently,

$$\gamma=\frac{3}{10}.$$

We have then

$$\frac{2\gamma}{1-2\gamma}=\frac{3}{2};$$

and (91) and (93) become

(94) $$\frac{v'}{v}=\left(\frac{f'a'\lambda}{fa\lambda'}\right)^{\frac{3}{10}},$$

(95) $$\frac{P'}{P}=\left(\frac{fa\lambda'}{f'a'\lambda}\right)^{\frac{3}{2}}.$$

Equation (94) enables us to compare the velocities given by powders having the same maximum pressure; the condition of equality of pressures is expressed by the equation,

(96) $$\frac{\tau}{\tau'}=\frac{fa}{f'a'}.$$

Equation (95) serves to compare the maximum pressures caused by powders giving the same velocity. Putting $\gamma = \frac{3}{10}$ in (92), we see that the characteristics of the powder are then connected by the relation,

$$(97) \qquad \frac{\tau}{\tau'} = \left(\frac{fa}{f'a'}\right)^{\frac{5}{2}} \left(\frac{\lambda'}{\lambda}\right)^{\frac{3}{2}}.$$

The various formulæ which precede can only be considered as approximate, owing to the uncertainty in the value of γ. We have found the value $\gamma = \frac{3}{10}$ from the exponent of the variable m in (90); now, it is easy to see that a very slight variation of this exponent will cause the value of γ, and particularly that of $\frac{2\gamma}{1 - 2\gamma}$, to change considerably.

Notwithstanding this, we believe that the relations furnished by theory may, with advantage, be applied to the study of ballistics, in place of the formulæ hitherto used, which have all been empirical.

72. To give an example, we shall compare the effects of two powders of the same make and differing in form and density of grain.

Take two powders, the grains of one being spheres and those of the other parallelopipeds. In the latter, let the base be a square, and the side of the base double the height. We have:

1st. For the sphere,

$$a = 3, \ \lambda = 1;$$

2d. For the parallelopiped,

$$a' = 2, \ \lambda' = \tfrac{5}{8}.$$

We therefore have from (94) and (95),

$$\frac{v'}{v} = \left(\frac{16}{15}\right)^{\frac{5}{10}} = 1.020,$$

$$\frac{P'}{P} = \left(\frac{16}{15}\right)^{\frac{5}{2}} = .908.$$

By the substitution of the parallelopiped for the sphere, we may therefore increase the velocity by $\frac{1}{50}$ about without changing the pressure, or diminish the pressure by about $\frac{1}{10}$ without changing the velocity.

In the first case, the ratio of the times of burning are, from (96),

$$\frac{\tau}{\tau'} = \frac{3}{2};$$

and, in the second case, from (97),

$$\frac{\tau}{\tau'} = \left(\frac{3}{2}\right)^{\frac{5}{2}} \left(\frac{5}{8}\right)^{\frac{3}{2}} = 1.362.$$

From the ratio of the times of combustion, we can deduce the number of grains to a kilogram.

For the spherical powder, let

r be the mean radius of grain,
δ the density of the powder,
v the velocity of combustion,
N the number of grains to the kilogram.

We have from No. 45

$$\tau = \frac{r}{v}, \quad r = \left(\frac{3}{4\pi\delta N}\right)^{\frac{1}{3}}.$$

Similarly for the second powder, calling δ', v', N', the homologous parts to δ, v, N, and a the height of the grain, we have from No. 45,

$$\tau' = \frac{a}{2v'}, \quad a = \left(\frac{1}{4\delta' N'}\right)^{\frac{1}{3}}.$$

The material of the two powders being the same, we have $v' = v$, $\delta' = \delta$, and consequently

$$\frac{\tau}{\tau'} = 2\left(\frac{3N'}{\pi N}\right)^{\frac{1}{3}}.$$

We deduce from this expression, and from the two values of $\frac{\tau}{\tau'}$ above, that,

1st. To obtain the same maximum pressure we must have

$$\frac{N'}{N} = 0.44 \ldots;$$

2d. To obtain the same velocity,

$$\frac{N'}{N} = 0.33 \ldots$$

73. *Application to a particular case.*—Wetteren powder (13 to 16 mill. grains), fired in the navy 24 cm. gun, in the ordinary conditions of *épreuves de réception*, gives about 437 meters velocity and 2500 kilos per square centimeter pressure.

The grains of this powder are irregular, and the mean number of grains to the kilogram is 350. Suppose that we substitute for it another powder of the same material, but whose grains are parallelopipeds with square bases and heights ½ the side of the square.

It results from what precedes:

1st. That, if the number of grains to the kilogram of the new powder is $350 \times .44 = 154$,

the initial velocity will be

$$437 \times 1.02 = 446 \text{ meters about,}$$

the pressure being the same as that of the Wetteren powder.

2d. That, if the number of grains to the kilogram is

$$350 \times .33 = 115,$$

the maximum pressure will be

$$2500 \times .908 = 2270 \text{ kilos about,}$$

the initial velocity being the same as that given by the Wetteren powder.

These results would be changed if the constants f, δ, v, differed for the two powders. The general formulæ, however, will permit our calculating the effect of these elements.

We shall return to these questions of application, which seem to have a certain importance from a practical standpoint.

CHAPTER V.

Numerical Determination of the Auxiliary Functions.

74. We have seen (No. 47) that the theoretical study of the movement of the projectile in the interior of a gun should be amended by the determination of certain functions purely numerical. These functions, which may be termed *auxiliaries*, are those which we have designated (No. 48) by the notation $y_0, y_1, y_2, \ldots$ We have remarked that they consist of special transcendentals, the complete numerical determination of which would permit the theoretical solution of all the problems relating to the firing of any gun, whatever may be the variable elements of the firing.

The auxiliary functions are defined by equation (67). It does not seem possible, in the actual state of the resources of analysis, to deduce the explicit form of the unknown functions of equations where they are involved not only under the characteristics of differentiation, but also under the signs of integration.

But we can apply to these equations the methods used for the numerical integration of differential equations. The application of these methods leads to long and laborious calculations, but does not present any theoretical difficulty. We will explain it briefly.

75. *Determination of the function y_0.*—We have designated by y_0 that one of the auxiliary functions which forms the first term of the development of the space traversed by the projectile as a function of the time taken to travel this space. It is defined by the first of equations (67), which we reproduce below, replacing X_0 by its value (65)

$$(98) \qquad (y_0+1)\frac{d^2y_0}{dx^2}+\theta\left(\frac{dy_0}{dx}\right)^2=\int_0^x\left(\frac{d^2y_0}{dx^2}\right)^a dx.$$

It should vanish also, as well as its first derivative for the value $x=0$. For small values of x we satisfy the equation (98) and also the initial conditions by putting:

$$(99)\begin{cases} \dfrac{d^2y_0}{dx^2}=ax^m+bx^n+cx^p+\ldots \\ \dfrac{dy_0}{dx}=\dfrac{a}{m+1}.x^{m+1}+\dfrac{b}{n+1}.x^{n+1}+\dfrac{c}{p+1}.x^{p+1}+\ldots \\ y_0=\dfrac{a}{(m+1)(m+2)}.x^{m+2}+\dfrac{b}{(n+1)(n+2)}.x^{n+2} \\ \qquad +\dfrac{c}{(p+1)(p+2)}.x^{p+2}+\ldots \end{cases}$$

$a, b, c, \ldots m, n, p, \ldots$ to be determined. Substituting the values (99) in equation (98) and identifying, we find for the exponents,

$$(100) \qquad m=\frac{1}{1-a}, \quad n=\frac{4-2a}{1-a}, \quad p=\frac{7-4a}{1-a}\ldots;$$

and the coefficients $a, b, c, \ldots$ are given by the equations

$$(101)\quad \begin{aligned} &a=\frac{1}{m^m}, \\ &\frac{a^2}{(m+1)(m+2)}+b+\theta\frac{a^2}{(m+1)^2}=\frac{am}{n}b, \\ &\frac{ab}{(m+1)(n+2)}+\frac{ab}{(n+1)(n+2)}+c+2\theta\frac{ab}{(m+1)(n+1)} \\ &\qquad=\frac{am}{p}c+\frac{a(a-1)m}{2p}\cdot\frac{b^2}{a}. \end{aligned}$$

The series (99) are very convergent for values of x less than unity. We can also deduce from them the values of y_0 and of its derivatives for $x=1$, but beyond $x=1$ they become rapidly divergent, and it becomes necessary to have recourse to Taylor's Theorem.

76. Suppose the functions $\frac{d^2y_0}{dx^2}$, $\frac{dy_0}{dx}$, y_0 calculated for a given value of x, the variable.

The increments of these functions corresponding to the increase h of the variable are given by the known developments:

$$(102)\quad \begin{cases} \Delta \dfrac{d^2y_0}{dx^2} = h\dfrac{d^2y_0}{dx^2} + \dfrac{h^2}{2}\cdot\dfrac{d^4y_0}{dx^4} + \dfrac{h^3}{6}\cdot\dfrac{d^5y_0}{dx^5} + \dots \\ \Delta \dfrac{dy_0}{dx} = h\dfrac{d^2y_0}{dx^2} + \dfrac{h^2}{2}\cdot\dfrac{d^3y_0}{dx^3} + \dfrac{h^3}{6}\cdot\dfrac{d^4y_0}{dx^4} + \dfrac{h^4}{24}\cdot\dfrac{d^5y_0}{dx^5} + \dots \\ \Delta y_0 = h\dfrac{dy_0}{dx} + \dfrac{h^2}{2}\cdot\dfrac{d^2y_0}{dx^2} + \dfrac{h^3}{6}\cdot\dfrac{d^3y_0}{dx^3} \\ \qquad\qquad + \dfrac{h^4}{24}\cdot\dfrac{d^4y_0}{dx^4} + \dfrac{h^5}{120}\cdot\dfrac{d^5y_0}{dx^5} + \dots \end{cases}$$

In order to make the calculations it is necessary to have the derivatives of y_0 of a superior order to the second. Differentiating several times equation (98) we obtain the system,

$$(103)\quad \begin{cases} (y_0+1)\dfrac{d^3y_0}{dx^3} + (1+2\theta)\dfrac{dy_0}{dx}\dfrac{d^2y_0}{dx^2} = \left(\dfrac{d^2y_0}{dx^2}\right)^{\alpha}, \\ (y_0+1)\dfrac{d^4y_0}{dx^4} + 2(1+\theta)\dfrac{dy_0}{dx}\cdot\dfrac{d^3y_0}{dx^3} + (1+2\theta)\left(\dfrac{d^2y_0}{dx^2}\right)^2 \\ \qquad = \alpha\left(\dfrac{d^2y_0}{dx^2}\right)^{\alpha-1}\cdot\dfrac{d^3y_0}{dx^3}, \\ (y_0+1)\dfrac{d^5y_0}{dx^5} + (3+2\theta)\dfrac{dy_0}{dx}\cdot\dfrac{d^4y_0}{dx^4} + (4+6\theta)\dfrac{d^2y_0}{dx^2}\cdot\dfrac{d^3y_0}{dx^3} \\ \qquad = \alpha(\alpha-1)\left(\dfrac{d^2y_0}{dx^2}\right)^{\alpha-2}\cdot\left(\dfrac{d^3y_0}{dx^3}\right)^2 + \alpha\left(\dfrac{d^2y_0}{dx^2}\right)^{\alpha-1}\dfrac{d^4y_0}{dx^4}, \\ \dots\dots\dots\dots\dots\dots \end{cases}$$

The first of these equations gives $\dfrac{d^3y_0}{dx^3}$, the second $\dfrac{d^4y_0}{dx^4}$ and so on for functions of derivatives of superior order. We can then calculate all the coefficients of the developments (102).

We deduce the values of y_0, $\dfrac{dy_0}{dx}$, $\dfrac{d^2y_0}{dx^2}$, for the value $x+h$ of the variable; next those corresponding to $x+2h$, and so on, step by step.

We can also, following the degree of convergence of the series (102), supposed to be reduced to the same number of terms, modify the numerical value of the increase h of the variable.

77. Passing to the numerical calculation it is necessary to have given the values of α and θ. We have made the calculation, supposing α to be $\frac{1}{2}$, according to No. 37, and $\theta = \frac{1}{5}$, following the second hypothesis of No. 20, and we have formed the following table, giving the corresponding values of y_0 and of its first and second derivatives.

	Values of		
x	y_0	$\frac{dy_0}{dx}$	$\frac{d^2y_0}{dx^2}$
1.00	0.021	0.082	0.242
1.25	0.050	0.158	0.363
1.50	0.102	0.264	0.485
1.75	0.184	0.399	0.591
2.00	0.303	0.557	0.666
2.25	0.464	0.729	0.704
2.50	0.668	0.906	0.709
2.75	0.917	1.082	0.690
3.00	1.208	1.250	0.657
3.25	1.541	1.409	0.617
3.50	1.912	1.558	0.574
3.75	2.319	1.697	0.533
4.00	2.760	1.825	0.494
4.50	3.731	2.055	0.427
5.00	4.809	2.254	0.372
5.50	5.981	2.429	0.329
6.00	7.235	2.584	0.294
6.50	8.562	2.724	0.265
7.00	9.956	2.850	0.241
8.00	12.925	3.072	0.205
9.00	16.095	3.263	0.179
10.00	19.443	3.421	0.158

78. *Determination of the function* y_1.—The function y_1 furnishes the second term of the development (64). It is defined by the second of the equations (67), in which by replacing X_0 and X_1 by their values, (65) can be written

$$(104)\quad (y_0+1)\frac{d^2y_1}{dx^2}+2\theta\frac{dy_0}{dx}\cdot\frac{dy_1}{dx}+\frac{d^2y_0}{dx^2}y_1$$
$$=\alpha\int_0^x\frac{d^2y_1}{dx^2}\left(\frac{d^2y_0}{dx^2}\right)^{\alpha-1}dx-\lambda\left[\int_0^x\left(\frac{d^2y_0}{dx^2}\right)^{\alpha}dx\right]^2.$$

The function y_1 should satisfy this equation and should vanish, as also its first derivative for $x=0$.

In order to determine it numerically we proceed as in the case of y_0.

For small values of x, y_0 and its first and second derivatives are represented by the developments (99). Equation (104) is satisfied then by representing the ratios of y_1 and its derivatives to λ by analogous developments, that is to say, by putting

$$(105)\quad \begin{cases} \dfrac{1}{\lambda}\cdot\dfrac{d^2y_1}{dx^2}=a_1x^{m_1}+b_1x^{n_1}+c_1x^{p_1}+\dots \\ \dfrac{1}{\lambda}\cdot\dfrac{dy_1}{dx}=\dfrac{a_1}{m_1+1}x^{m_1+1}+\dfrac{b_1}{n_1+1}x^{n_1+1} \\ \qquad\qquad +\dfrac{c_1}{p_1+1}x^{p_1+1}+\dots \\ \dfrac{1}{\lambda}y_1=\dfrac{a_1}{(m_1+1)(m_1+2)}x^{m_1+2} \\ \qquad\qquad +\dfrac{b_1}{(n_1+1)(n_1+2)}x^{n_1+2}+\dots \end{cases}$$

$a_1, b_1, c_1, \dots; m_1, n_1, p_1, \dots$ to be determined. Substituting the values (99) and (105) in the equation (104) and identifying similar powers of x, we find the following values of the exponents:

$$(106)\qquad m_1=2m,\quad n_1=n+m,\quad p_1=p+m,$$

and recollecting the values (100),

$$(107)\qquad m_1=\frac{2}{1-\alpha},\quad n_1=\frac{5-2\alpha}{1-\alpha},\quad p_1=\frac{8-4\alpha}{1-\alpha}\dots$$

The system of equations which determines the coefficients a_1, b_1, $c_1, \dots$ is the following

$$(108)\quad \begin{cases} a_1\left(1-\dfrac{\alpha a^{\alpha-1}}{m_1}\right)+\dfrac{a^{2\alpha}}{m^2}=0 \\ Aa_1+b_1\left(1-\dfrac{\alpha a^{\alpha-1}}{n_1}\right)+\dfrac{2\alpha b a^{2\alpha-1}}{mn}=0 \\ Ba_1+Cb_1+c_1\left(1-\dfrac{\alpha a^{\alpha-1}}{p_1}\right)+D=0; \end{cases}$$

putting for brevity:

$$(109)\quad \begin{cases} A=\left[\dfrac{1}{(m+1)(m+2)}+\dfrac{2\theta}{(m+1)(m_1+1)} \right. \\ \qquad \left. +\dfrac{1}{(m_1+1)(m_1+2)}\right]a-\dfrac{\alpha(\alpha-1)ba^{\alpha-2}}{n}, \\ B=\left[\dfrac{1}{(n+1)(n+2)}+\dfrac{2\theta}{(n+1)(m_1+1)} \right. \\ \qquad \left. +\dfrac{1}{(m_1+1)(m_1+2)}\right]b-\dfrac{\alpha(\alpha-1)c^{\alpha-2}}{p_1} \\ \qquad -\dfrac{1}{2}\,\dfrac{\alpha(\alpha-1)(\alpha-2)b^2a^{\alpha-3}}{p_1}, \\ C=\left[\dfrac{1}{(m+1)(m+2)}+\dfrac{2\theta}{(m+1)(n_1+1)} \right. \\ \qquad \left. +\dfrac{1}{(n_1+1)(n_1+2)}\right]a-\dfrac{\alpha(\alpha-1)ba^{\alpha-2}}{p_1}, \\ D=\dfrac{2\alpha ca^{2\alpha-1}}{mp}+\dfrac{\alpha(\alpha-1)b^2a^{2\alpha-2}}{mp}+\dfrac{\alpha^2b^2a^{2\alpha-2}}{n^2}. \end{cases}$$

These formulæ permit the calculations of y_1, $\frac{dy_1}{dx}$, $\frac{d^2y_1}{dx^2}$ for $x = 1$ and for inferior values of the variable.

For values of x greater than unity the series (105) becomes rapidly divergent and cannot be employed.

It is necessary then to calculate by formula (102) the increments of increase of y_1, $\frac{dy_1}{dx}$, $\frac{d^2y_1}{dx^2}$, corresponding to the increase h of the variable. This calculation supposes the initial numerical values of derivatives of superior order to be known. They are obtained by taking the successive derivatives of equation (104).

The problem is then theoretically solved, but the numerical calculations being very long we have omitted them. This calculation also offers no real interest after we have fixed with some certainty the numerical values of the coefficients a and θ.

We hope to return again to this subject, and in the meantime present here some supplementary remarks on the function y_0, of which we have given the complete numerical calculation.

79. The numerical determination of y_0 permits the establishment of the laws of the initial movement of the projectile, since in the first instance the value of the first term of the series which represents the displacement is preponderating.

It should also be remarked that an error in the value of θ has not then a very sensible influence because of the relatively small value of the second term of equation (98).

The table of No. 77 can then furnish some useful indications of the law which regulates the interior pressure near the maximum, which is produced as we know when the projectile is displaced only a fraction, generally very small, of the length of the bore.

In view of these applications, it is convenient to change the independent variable, and to form a table of the corresponding values of $\frac{d^2y_0}{dx^2}$ and y_0.

We obtain thus the numerical determination of the function $\varphi_0\left(\frac{u}{z}\right)$ which, according to formula (75), serves to calculate the pressure p corresponding to the space u passed over by the projectile.

This calculation offers no difficulty. It is effected very simply by constructing, by the aid of the table of No. 77, a curve having for abscissae y_0 and for ordinates the corresponding values of $\frac{d^2y_0}{dx^2}$. We

deduce graphically by this interpolation the figures of the following table:

y_0	$\frac{d^2y_0}{dx^2}$	y_0	$\frac{d^2y_0}{dx^2}$	y_0	$\frac{d^2y_0}{dx^2}$
0.1	0.480	0.6	0.710	1.25	0.651
0.2	0.605	0.7	0.705	1.50	0.621
0.3	0.665	0.8	0.700	1.75	0.590
0.4	0.693	0.9	0.692	2.00	0.563
0.5	0.700	1.0	0.680	2.50	0.513

It is superfluous to prolong this table for greater values of y_0; the influence of the second term which depends on y_1 becomes more and more sensible, and the value of $\frac{d^2y_0}{dx^2}$ ceases to represent the interior pressure with a sufficient approximation.

We recollect that the variable y_0 represents, in the order of approximation adopted, the ratio $\frac{u}{z}$ of the displacement of the projectile to the *reduced length of the initial air space*, which is calculated according to (18) by the formula:

$$z = u_0\left(1 - \frac{\Delta}{\delta}\right),$$

in which we designate by

u_0 the reduced length of the powder chamber;*

Δ the density of loading;

δ the density of the powder.

80. *Maximum pressure, displacement of the projectile.*—We see by an inspection of the curve which serves to establish the preceding table:

1st. That the maximum of $\frac{d^2y_0}{dx^2}$ is equal to 0.710;

2d. That the corresponding value of y_0 is very nearly 0.6.

The first of these results shows a remarkable verification. The maximum value which we find theoretically equal to 0.710 is that of the coefficient A of No. 63. Now in determining this coefficient by the aid of the experiments furnished by the firing of a 24 centimeter gun, we find $A = 0.703$, a number which differs very little from the preceding.

If, then, in the circumstances of firing in question, we admit *a priori* formula (88), attributing to A the theoretical value 0.710, and

* Defined in No. 18.

to the quantities f and τ the particular values of No. 64, the calculation gives for the maximum pressure a value which differs very little from that obtained by the use of crusher gauges.

Again, the theoretical value of f, deduced by formula (2) from the temperature of combustion and from the volume of the permanent gases of the powder, and the value of τ being the duration of combustion of the grain under the normal atmospheric pressure, we conclude that theory permits us to compute the maximum pressure, in this particular case, when we know the following elements of which the determination can be made by simple experiments in the laboratory:

1st. The heat of combustion of the powder;

2d. The volume (reduced to zero and at 0.760 m.) of the permanent gases produced;

3d. Its velocity of combustion in free air.

It would be interesting to ascertain if this agreement of theory and experiment, of which the true determination is always subordinate to the measure of precision of crusher gauges, is maintained under different conditions of firing from those in which we have verified it.

81. We deduce finally from what precedes a very important result. The maximum pressure is produced when the ratio of the displacement of the projectile to the reduced length of the initial air space is equal to 0.6. Consequently denoting by U the displacement corresponding to the maximum, we have very nearly:

$$U = 0.6 u_0 \left(1 - \frac{\Delta}{\delta} \right). \tag{110}$$

On the other hand, this result should be considered as approximate only (See No. 54). But the approximation is sufficient, we believe, in the greater number of cases.

Example. In a 24 centimeter gun, fired under the ordinary conditions of powder proof, we have (the decimeter being taken for the unit): $u_0 = 7.63$, $\Delta = 0.800$, $\delta = 1.800$,
and consequently: $U = 2.54$.

82. *Case in which the first auxiliary equation is integrable.*—The equation (98) becomes integrable when the exponent α reduces to unity. This case would be realized if the velocity of combustion of the powder was proportional to the exterior pressure. There is reason to suppose that the velocity of combustion increases less rapidly than the pressure, and the case which we show is consequently purely theoretical. It offers, however, some interest because the first auxiliary function being then taken in explicit form, we are able to judge,

with a precision which is not obtained by the method of numerical approximation which we have employed, of the general aspect of this function in this real case.

Making $\alpha = 1$, equation (98) reduces to the following:

$$(y_0 + 1)\frac{d^2 y_0}{dx^2} + \theta\left(\frac{dy_0}{dx}\right)^2 = \frac{dy_0}{dx},$$

or better, putting

$$\frac{dy_0}{dx} = v,$$

$$(y_0 + 1)\frac{dv}{dx} + \theta v^2 = v.$$

We have also:

$$\frac{dv}{dx} = \frac{dv}{dy_0} \cdot \frac{dy_0}{dx} = v\frac{dv}{dy_0}.$$

Substituting and dividing by v we have

$$(y_0 + 1)\frac{dv}{dy_0} + \theta v = 1,$$

whence

$$\frac{dv}{\theta v - 1} + \frac{dy_0}{y_0 + 1} = 0,$$

and integrating:

$$(\theta v - 1)(y_0 + 1)^\theta = \text{constant}.$$

The constant is determined by the condition $v = 0$, for $y_0 = 0$. It is equal to -1. We have consequently:

$$v = \frac{1}{\theta}\left[1 - \frac{1}{(y_0 + 1)^\theta}\right]. \tag{111}$$

We find from it by quadrature the relation between x and y_0. The second derivative $\frac{d^2 y_0}{dx^2}$ is obtained by multiplying the value of v by its derivative with respect to y_0.

$$\frac{d^2 y_0}{dx^2} = \frac{1}{\theta}\left[\frac{1}{(y_0 + 1)^{\theta+1}} - \frac{1}{(y_0 + 1)^{2\theta+1}}\right], \tag{112}$$

the value of y_0, which gives the maximum, is obtained from the relation:

$$\frac{1}{y_0 + 1} = \left(\frac{\theta + 1}{2\theta + 1}\right)^{\frac{1}{\theta}},$$

and the corresponding value of $\frac{d^2 y_0}{dx^2}$ is:

$$A = \frac{1}{\theta}\left[\left(\frac{\theta + 1}{2\theta + 1}\right)^{\frac{\theta+1}{\theta}} - \left(\frac{\theta + 1}{2\theta + 1}\right)^{\frac{2\theta+1}{\theta}}\right].$$

On the other hand, in this simple case, the function y_1 does not appear obtainable in an explicit form.

PART IV.

PRACTICAL FORMULÆ FOR VELOCITIES AND PRESSURES IN GUNS.

PREFACE.

In a preceding memoir published in 1876 was established the necessary form of the formulæ which represent the initial velocity and the maximum pressure produced in guns.

We shall take account in this Part of the various circumstances which influence the effects obtained, and notably, the variation that the velocity of the combustion of powder presents under variable pressure.

The formulæ indicate, moreover, the law according to which the results of firing depend upon the form of the grain; an element, the influence of which has become preponderating since the employment, very nearly general to-day, of progressive powders.

In the present memoir will be fixed the numerical value of the coefficients in a way to render the formulæ immediately applicable to the calculation of the various conditions of practice. This determination is made the object of the first chapter.

In Chapter II the formulæ will be verified by the comparison of calculated and measured results, and it will be shown that they represent seventy-five very different conditions of firing, in guns which vary in calibre from 320 to 75 millimeters, with a mean difference of velocities less than 3 meters, the velocities varying from 300 to 550 meters.

Chapter III is devoted to the development of some consequences of the theory, and to the examination of some questions of interior ballistics which have not hitherto been studied, except in an empirical manner.

CHAPTER I.

FORMULÆ FOR VELOCITIES AND PRESSURES.

1. *Formula for velocities.*—In a preceding part the general form of the expression for the initial velocity produced in a gun by the combustion of progressive powder has been shown.

This formula was obtained by supposing the velocity of combustion of the powder to be proportional to a positive power of the pressure. In what follows this power is taken equal to ½. This value is indicated also by theoretical considerations (Art. 36, Part III), and leads, as will be seen later, to the formulæ which accord with the facts.

Under this hypothesis, the expression for the velocity is the following [Eq. (89), Part III]:

$$(1) \qquad v = \left(\frac{fa\varpi}{\tau m}\right)^{\frac{1}{2}} \left(\frac{mz}{\omega p_0}\right)^{\frac{1}{4}} \left[\varphi_0\left(\frac{u}{z}\right) - \frac{\lambda}{\tau}\left(\frac{mz}{\omega p_0}\right)^{\frac{1}{2}} \varphi_1\left(\frac{u}{z}\right)\right],$$

designating by

ϖ the weight of the charge of powder,

m the mass of the projectile,

u the length of the path of the projectile (this length is the distance which separates, at the position of loading, the base of the projectile from the face of the muzzle. This is the length, and not the total length of the bore, which directly influences the velocity),

ω the right section of the bore,

z the reduced length of the initial air space. (*Initial air space* is the difference between the volume of the powder chamber and the volume of the powder. The *reduced length* corresponding is measured by the height of a cylinder having for a base the right section of the bore and for a volume that of the *initial air space*),

f the force of the powder. (The force of a powder is the pressure of the gases of 1 kilogram of that powder occupying, at the temperature of combustion, the unit of volume. See Art. 61, Part II),

p_0 the normal atmospheric pressure,

τ the duration of the combustion of a grain of powder under the pressure p_0,

a, λ numerical coefficients depending upon the form of the grain (these values for various forms of grains will be found, Articles 39, 40, 41, Part III);

φ_0, φ_1 are purely numerical functions.

The reduced length of the *initial air space* is calculated by formula

$$(2) \qquad z = \frac{\varpi}{\omega}\left(\frac{1}{\Delta} - \frac{1}{\delta}\right), \text{ [See Part III, (19)]}$$

in which we call:

Δ the density of loading,

δ the real density of the powder.

2. The theoretical determination of the functions φ_0 and φ_1 offers some difficulties which have been shown in Chapter V, Part III. But this determination is not indispensable for the applications which we have in view, and we can, as will be seen, deduce from the relation (1) a formula which suffices for the wants of practice.

3. Whatever may be the analytical expressions for φ_0 and φ_1, these functions are such that they become respectively proportional to the $\frac{1}{4}$ and $\frac{3}{4}$ powers of $\frac{u}{z}$ for infinitely great values of that variable.

This condition results from the analytical discussion of the equations which define these auxiliary functions.

Also we observe that the two terms of expression (1), respectively proportional to $z^{\frac{1}{4}}$ and $z^{\frac{3}{4}}$, remain finite for infinitely small values of z.

So that we have, when $\frac{u}{z}$ is very great,

$$(3) \qquad \varphi_0\left(\frac{u}{z}\right)=A_0\left(\frac{u}{z}\right)^{\frac{1}{4}}, \quad \varphi_1\left(\frac{u}{z}\right)=A_1\left(\frac{u}{z}\right)^{\frac{3}{4}},$$

A_0 and A_1 representing numerical coefficients.

4. This being granted, we write formula (1) as follows:

$$(4) \qquad v=\left(\frac{fa\varpi}{\tau m}\right)^{\frac{1}{2}}\left(\frac{mz}{\omega p_0}\right)^{\frac{1}{4}}\varphi_0\left(\frac{u}{z}\right)\left[1-\frac{\lambda}{\tau}\left(\frac{mz}{\omega p_0}\right)^{\frac{1}{2}}\frac{\varphi_1\left(\frac{u}{z}\right)}{\varphi_0\left(\frac{u}{z}\right)}\right].$$

In the ordinary conditions of practice, the ratio $\frac{u}{z}$ has a large value; on the other hand, the second term of the quantity between brackets is generally a fraction much smaller than unity. We can, therefore, substitute approximately for the ratio $\frac{\varphi_1}{\varphi_0}$ the value which it approaches for increasing values of $\frac{u}{z}\cdot$ From equation (3) we have then very nearly

$$\frac{\varphi_1\left(\frac{u}{z}\right)}{\varphi_0\left(\frac{u}{z}\right)}=Q\left(\frac{u}{z}\right)^{\frac{1}{2}}.$$

Admitting this hypothesis, and supposing, further, that the function φ_0 is sensibly proportional within certain limits to a power γ of the variable, that is to say, putting:

$$\varphi_0\left(\frac{u}{z}\right)=P\left(\frac{u}{z}\right)^{\gamma},$$

it becomes:

$$v = P\left(\frac{fa\varpi}{\tau m}\right)^{\frac{1}{2}}\left(\frac{mz}{\omega p_0}\right)^{\frac{1}{4}}\left(\frac{u}{z}\right)^{\gamma}\left[1 - Q\frac{\lambda}{\tau}\left(\frac{mu}{\omega p_0}\right)^{\frac{1}{2}}\right],$$

or better still, replacing z by its value (2),

$$(5) \quad v = Pp_0^{-\frac{1}{4}}\left(\frac{fa}{\tau}\right)^{\frac{1}{2}}\left(\frac{\varpi}{m}\right)^{\frac{1}{4}}\left(\frac{\varpi}{\omega}\right)^{\frac{1}{2}-\gamma}$$
$$\left(\frac{1}{\Delta} - \frac{1}{\delta}\right)^{\frac{1}{4}-\gamma} u^{\gamma}\left[1 - Q\frac{\tau}{\lambda}\left(\frac{mu}{\omega p_0}\right)^{\frac{1}{2}}\right].$$

5. Designating by p the weight of the projectile, c the calibre or diameter of the bore, g the acceleration of the force of gravity, we have:

$$m = \frac{p}{g}, \quad \omega = \frac{\pi c^2}{4}.$$

Substituting these values in expression (5) and putting for brevity:

$$A = P\left(\frac{g}{p_0}\right)^{\frac{1}{4}}\left(\frac{4}{\pi}\right)^{\frac{1}{2}-\gamma}, \quad B = Q\left(\frac{4}{\pi g p_0}\right)^{\frac{1}{2}},$$

it becomes:

$$(6)\ v = A\left(\frac{fa}{\tau}\right)^{\frac{1}{2}}\left(\frac{\varpi}{p}\right)^{\frac{1}{4}}\left(\frac{\varpi}{c^2}\right)^{\frac{1}{2}-\gamma}\left(\frac{1}{\Delta} - \frac{1}{\delta}\right)^{\frac{1}{4}-\gamma} u^{\gamma}\left[1 - B\frac{\lambda}{\tau}\frac{(pu)^{\frac{1}{2}}}{c}\right].$$

6. In order to obtain a formula which shall be numerically applicable, it remains to fix the value of γ. It can be obtained from the results of experiments. In fact, the empirical formulæ of the commission of Gavre established the fact that, all other elements being constant, the initial velocity is:

1st. Proportional to the $\frac{6}{10}$ power of the charge (Memorial de l'artillerie de la Marine, Vol. IV, pp. 25 and 45).

2d. Inversely proportional to the $\frac{1}{4}$ power of the capacity S' in which the powder charge is placed (Mem. de l'art. de la Mar., Vol. II, p. 37).

The velocity v is then approximately proportional to

$$\frac{\varpi^{\frac{6}{10}}}{S'^{\frac{1}{4}}} = \varpi^{\frac{6}{10}-\frac{1}{4}}\Delta^{\frac{1}{4}}.$$

Now according to formula (6), the velocity v is proportional to

$$\varpi^{\frac{3}{4}-\gamma}\left(\frac{1}{\Delta} - \frac{1}{\delta}\right)^{\frac{1}{4}-\gamma}.$$

Comparing these two results, we conclude,

1st. That we should have very nearly,

$$\frac{3}{4} - \gamma = \frac{6}{10} - \frac{1}{4},$$

hence
$$\gamma = \frac{4}{10};$$

2d. That the quantity:
$$\left(\frac{1}{\Delta} - \frac{1}{\delta}\right)^{\frac{1}{4}-\gamma} = \left(\frac{\delta\Delta}{\delta - \Delta}\right)^{\frac{3}{20}}$$

should be, for values of δ and Δ, comprised between the limits of practice, sensibly proportional to $\Delta^{\frac{1}{4}}$, and this is also verified numerically.

We are then led to the formula:

$$(7) \qquad v = A\left(\frac{fa}{\tau}\right)^{\frac{1}{2}}\left(\frac{\varpi}{p}\right)^{\frac{1}{4}}\left(\frac{\varpi}{c^2}\right)^{\frac{1}{10}}\left(\frac{\delta\Delta}{\delta - \Delta}\right)^{\frac{3}{20}} u^{\frac{4}{10}}\left[1 - B\frac{\lambda}{\tau}\cdot\frac{(pu)^{\frac{1}{2}}}{c}\right],$$

which we can in practical applications replace by the following:

$$(8) \qquad v = A\left(\frac{fa}{\tau}\right)^{\frac{1}{2}}\left(\frac{\varpi}{p}\right)^{\frac{1}{4}}\left(\frac{\varpi}{c^2}\right)^{\frac{1}{10}}\Delta^{\frac{1}{4}}u^{\frac{4}{10}}\left[1 - B\frac{\lambda}{\tau}\,\frac{(pu)^{\frac{1}{2}}}{c}\right].$$

This last equation is more simple and sufficiently exact. We shall adopt it in our last researches. (Formula (8) does not take into account, as in formula (7), the variations of δ; but these variations are so small that in practice their influence on the velocity may be neglected.)

7. *Characteristics of a powder.*—Formula (8) includes two quantities $\left(\frac{fa}{\tau}\right)^{\frac{1}{2}}$ and $\frac{\lambda}{\tau}$, whose values depend upon the nature of the powder and upon the form and dimensions of the grains. These two elements completely determine the effect produced by a powder under given conditions. We can, then, call them *characteristics*. We will designate them hereafter by the letters α, β, putting:

$$(9) \qquad \alpha = \left(\frac{fa}{\tau}\right)^{\frac{1}{2}}, \quad \beta = \frac{\lambda}{\tau}.$$

8. *Numerical determination of the constants A and B.*—Supposing the characteristics of a given powder to be known, it suffices to measure the velocities given by this powder under two different conditions of firing, in order to find the numerical values of A and B from formula (8). This amounts to replacing successively the various elements in the formula by the particular values relating to the two firings, giving to v the corresponding values determined by experiment, and we have two equations showing the relation between the two unknown quantities A and B.

9. In the absence of precise data on the absolute values of α and β, we may take them equal to 1 for a well-defined powder, and refer the characteristics of other powders to those of the powder adopted as a *standard.* From this point of view we take, for example, as a standard a sample of Wetteren powder (grains of 13 to 16 millimeters), which under the normal conditions of proof firing has given in the 24 and 14 centimeter guns initial velocities respectively of 4371 and 4384 decimeters.

The numerical values of the various elements of firing are shown in the following table:

Name of Gun.	c decim.	u decim.	p kil.	ϖ kil.	Δ	v decim.
24 cent.	2.42	38.19	144	28	0.789	4371
14 cent.	1.40	27.04	21	4	0.891	4384

Putting successively the particular values from this table in formula (8) and replacing $\frac{fa}{\tau}$ and $\frac{\lambda}{\tau}$ by 1, we obtain two equations from which we find the values

$$(10)\qquad A = 2088,\quad B = 0.01089.$$

Consequently for any powder whatever of characteristics α and β the formula for velocities is the following:

$$(11)\qquad v = 2088\alpha\left(\frac{\varpi}{p}\right)^{\frac{1}{4}}\left(\frac{\varpi}{c^2}\right)^{\frac{1}{10}}\Delta^{\frac{1}{4}}u^{\frac{4}{10}}\left[1 - 0.01089\beta\frac{(pu)^{\frac{1}{2}}}{c}\right],$$

units: *decimeter, kilogram, second.*

10. In place of taking α and β equal to unity for the standard powder, we may calculate the numerical values of these quantities according to certain particular values of f, τ, a, and λ. These last quantities are it is true imperfectly known, but no error will result in the calculation of velocities, since we only change the units to which the characteristics of a powder are referred.

This method of working has the advantage of taking into account in the valuation of characteristics the physical signification of the elements on which they depend. It permits also, in certain cases, the establishment *à priori* and independently of all experiment, the values of the characteristics due to the physical properties of the powder. We shall give hereafter some examples.

In order to determine the constants A and B under this hypothesis, we adopt for the standard powder the values:

$$(12)\qquad f = 431000,\ \tau = 0.730,\ a = 3,\ \lambda = 1.$$

[The standard powder is composed as follows: saltpetre 75 parts, charcoal 12.5 parts, and sulphur 12.5 parts. Its specific constants are the following:

Number of grains to the kilogram, ... $N = 350$
Density in mercury, ... $\delta = 1.75$
Velocity of combustion under normal pressure (decimeters) $w = 0.10$

The grain is very irregular, but the mean form is supposed to be a sphere of radius r, and given by the formula

$$r = \left(\frac{3}{4\pi\delta N}\right)^{\frac{1}{3}}.$$

The duration of combustion is deduced from the equation: $\tau = \dfrac{r}{w}$.

The value $f = 431000$ is that adopted for cannon powder (No. 61, Part III). The values $\alpha = 3$, $\lambda = 1$ are for spherical grains (No. 39, Part III)].

By equation (9) the characteristics of this powder are deduced,

(13) $$\alpha_0 = 1331, \quad \beta_0 = 1.370,$$

and the new constants A and B are found by dividing equation (10) by α_0, β_0, we have thus:

(14) $$A = 1.569, \quad B = 0.00795,$$

consequently the formula for velocities as a function of all the elements of firing becomes

(15) $$v = 1.579\alpha\left(\frac{\varpi}{p}\right)^{\frac{1}{4}}\left(\frac{\varpi}{c^2}\right)^{\frac{1}{10}}\Delta^{\frac{1}{4}}u^{\frac{4}{10}}\left[1 - 0.00795\beta\frac{(pu)^{\frac{1}{2}}}{c}\right].$$

This formula constitutes the definite result we had in view. We give in succeeding chapters numerous applications of this formula.

The signification of the letters on which it depends has been given in Articles 2, 5, and 7. It is essential to recollect that the units adopted are the decimeter, the kilogram, and the second. (In the original formula (5) the constants P and Q are absolute numbers, independent of the choice of units. In formula (8) however the values of the constants A and B defined by the relations of No. 5 depend upon the units cited above.)

11. *Formula of pressures.*—Supposing the velocity of combustion proportional to the square root of the pressure under which it takes place, the maximum of the mean interior pressure is given by the formula:

(16) $$P = A\,\frac{fa}{\tau\omega}\left[\frac{m\varpi\delta\Delta}{p_0(\delta - \Delta)}\right]^{\frac{1}{2}},$$

in which A denotes a numerical factor independent of the choice of units, the signification of the other letters being the same as for formula (15). (See Part III, Nos. 63 and 64. In Part III, Art. 64, the value of A deduced from experiment is given as 0.703, admitting for the Wetteren powder $\tau = 0.6$. This number corresponds to a velocity of combustion of 11.7 millimeters per second. Some results recently obtained, however, lead us to admit that this velocity is in reality nearly 10 millimeters. This value which has served to establish the constants of formula (15) will be adopted in the calculations of pressures.)

Replacing, as in No. 5, m and ω by their values as functions of p and c, designating by K the product of A and all the constant factors of the formula, and observing finally that $\frac{fa}{\tau}$ is the square of the characteristic α defined in No. 7, it becomes

$$P = K\alpha^2 \frac{(p\varpi)^{\frac{1}{2}}}{c^2} \left[\frac{\delta\Delta}{\delta - \Delta}\right]^{\frac{1}{2}}. \tag{17}$$

12. This formula, already very simple, may be still further simplified by remarking that for the usual values of δ and Δ, the function $\left[\frac{\delta\Delta}{\delta - \Delta}\right]^{\frac{1}{2}}$ is very nearly proportional to Δ. Adopting this interpolation, which is quite sufficient for practice, the approximate formula for pressures is

$$P = K\alpha^2 \Delta \frac{(p\varpi)^{\frac{1}{2}}}{c^2}, \tag{18}$$

and under this form we shall employ it in the researches to follow.

13. *Numerical determination of K.*—Supposing the characteristic α of a powder to be known, it is sufficient to measure the maximum pressure for that powder given under a single condition of firing, in order to find from formula (18) the numerical value of the constant K.

For example, this determination can be made for the standard powder referred to in No. 9. This powder fired under the conditions defined in the table of the article before cited, has given pressures which, expressed in kilograms per square centimeter, are equal to

2290 kil. in the 24 cent. gun,
1140 " " 14 "

(These numbers are the means of the readings of three crusher gauges placed in the powder chamber.)

Consequently with our units the values of P in these two cases are respectively equal to 229000 and 114000. With these numbers two

values of K are deduced which differ but little from each other, and which give a remarkable verification of formula (18).

14. These values may be calculated in two ways:

1st. By supposing, as in Art. 9, $\alpha = 1$ for the standard powder. We find K to be:

$$(19)\qquad \left\{\begin{array}{lll} \text{For the 24 cent. gun} & . & K = 26760 \\ \text{" 14 " "} & . & K = 27360 \end{array}\right\} \text{mean: } 27060.$$

2d. By supposing, as in Art. 10, $\alpha = 1331$ for the standard powder. Under this hypothesis, we are led to divide by the square of α_0 the preceding value of K, which gives for the new value of K

$$(20)\qquad K = 0.0153.$$

The corresponding formulæ for P are:

$$(21)\qquad P = 27060\alpha^2 \Delta \frac{(p\varpi)^{\frac{1}{2}}}{c^2},$$

$$(22)\qquad P = 0.0153\alpha^2 \Delta \frac{(p\varpi)^{\frac{1}{2}}}{c^2}.$$

15. For reasons given in Art. 10, we are led to prefer and to adopt formula (22).

In the preceding formulæ for pressures as in those for velocities the units chosen are the decimeter, the kilogram, and the second. It is necessary then to divide the results of formula (22) by 100, if we wish, as is customary, to express the pressure in kilograms per square centimeter.

CHAPTER II.

Applications and Numerical Verifications.

16. In this chapter we shall show how by the preceding formulæ we may determine the characteristics of various powders, and make use of these determinations to calculate *à priori* the velocities and pressures in any arm whatever. The results will be compared with the results of direct measurement.

17. *Experimental determination of the characteristics.*—For the same powder, characterized by a system of values α, β, the initial velocity depends upon the five quantities,

$$c,\ u,\ p,\ \varpi,\ \Delta,$$

and is connected with them by (15).

It is evident from the form of this equation, that α and β will become known from two velocities determined by experiment with different systems of particular values of the variables, provided that one at least of the first three shall have different values in the two experiments.

Put for shortness,

$$(23)\qquad 1.569\left(\frac{\varpi}{p}\right)^{\frac{1}{4}}\left(\frac{\varpi}{c^2}\right)^{\frac{1}{10}}\Delta^{\frac{1}{4}}u^{\frac{4}{10}}=\frac{1}{X},\quad 0.00795\,\frac{(pu)^{\frac{1}{2}}}{c}=Y;$$

equation (15) may then be written

$$Xv=\alpha-\alpha\beta Y.$$

Calling X_1, Y_1; X_2, Y_2, two systems of values of X and Y, and v_1 and v_2 the corresponding measured velocities, we have

$$(24)\qquad \begin{cases} X_1v_1=\alpha-\alpha\beta Y_1, \\ X_2v_2=\alpha-\alpha\beta Y_2; \end{cases}$$

from which $\alpha\beta$ and α may be found by the relations,

$$\alpha\beta=\frac{X_2v_2-X_1v_1}{Y_1-Y_2},$$

$$\alpha=X_1v_1+\alpha\beta Y_1.$$

18. *On the error committed in the determination of the characteristics.*—It is easy to determine the effect of an error in the measurement of the velocities upon the determination of the characteristics. Consider the values of $\alpha\beta$ and α in the form

$$\alpha\beta=\frac{X_2v_2-X_1v_1}{Y_1-Y_2},$$

$$\alpha=\frac{Y_1X_2v_2-Y_2X_1v_1}{Y_1-Y_2}.$$

Let ε be the absolute value of the greatest error which is to be apprehended in the measurement of the velocities. The error corresponding in $\alpha\beta$ and α is a maximum when the error ε affects v_2 and v_1 in opposite senses. We have, consequently, the two limits,

$$(25)\qquad \varepsilon_1=\frac{X_2+X_1}{Y_1+Y_2}\varepsilon,\qquad \varepsilon_2=\frac{Y_1X_2+Y_2X_1}{Y_1-Y_2}\varepsilon.$$

The first concerns $\alpha\beta$, and the second α. It is evident from these values that Y_1-Y_2 should be made as large as possible by the choice of proper conditions of fire.

19. *Determination of the characteristics by firing guns of* 14 *and* 24 *centimeters.*—Firing these guns, in the conditions specified in No. 9, will answer very well for this determination. The numerical values of X and Y, calculated by (23), making use of the elements in the table of No. 9, are as follows:

$$\text{24 cent. gun} \begin{cases} X_1 = 0.20287, \\ Y_1 = 0.24362, \end{cases}$$

$$\text{14 cent. gun} \begin{cases} X_2 = 0.24735, \\ Y_2 = 0.13534. \end{cases}$$

The limits of error are given by the formulæ,

$$\varepsilon_1 = 3.99\varepsilon, \qquad \varepsilon_2 = 0.810\varepsilon;$$

in which ε, as well as the velocities, should be expressed in decimeters.

The following table shows the results of determinations made by this method upon various lots of powder tried by the committee at Gavre. These powders were all mixed in the proportions used in England (75 saltpetre, 10 sulphur, and 15 charcoal); and were fabricated with *meules et presses*.

Name of Powder.	Velocity with gun of 24 cent.	14 cent.	Values of α	β
A_5B.	439.7	441.6	1340	1.376
A_5S_1, No. 1, . .	453.8	464.1	1431	1.464
" " 2, . .	451.0	457.4	1401	1.425
" " 3, . .	446.7	447.8	1359	1.358
" " 4, . .	431.1	432.3	1312	1.370
" " 5, . .	412.2	478.2	1059	0.863

20. *Determination of the characteristics by firing with different projectiles.*—In the absence of guns of different calibres the characteristics may be determined by firing different projectiles in the same piece. We might, for example, measure the velocities of the 96 and 144 kilo. projectiles from the 24 cent. gun, the other elements being as defined in No. 9. We have in this case,

$$\text{96 kilo. projectile,} \begin{cases} X_1 = 0.18332, \\ Y_1 = 0.19890. \end{cases}$$

$$\text{144 kilo. projectile,} \begin{cases} X_2 = 0.20287, \\ Y_2 = 0.24362; \end{cases}$$

the limits of error are

$$\varepsilon_1 = 8.64\varepsilon, \qquad \varepsilon_2 = 1.90\varepsilon;$$

these are less favorable to accuracy than in the first method.

21. *Approximate determination of the force and velocity of combustion of powder.*—When the form of the grain is well defined, α and λ may be determined from (9). We may then determine f and τ, after the determination of a and β, by the formulæ

$$\tau = \frac{\lambda}{\beta}, \quad f = \frac{\tau a^2}{\alpha}. \tag{26}$$

The time of combustion τ is the time in free air. We have for the corresponding velocity of combustion,

$$w = \frac{e}{2\tau}, \tag{27}$$

e being the least dimension of the grain.

Let us apply this to the powders treated of in No. 19. Their grain is very nearly a parallelopipedon with square base. Their least dimension (thickness) is exactly regulated by the caking, and can be directly measured. The ratio of the other dimensions to the last can be calculated as a function:

1st. Of the thickness e;

2d. Of the number of grains in a kilogram N;

3d. Of the density δ,

by the formula (Part III, No. 45),

$$x = (\delta N)^{\frac{1}{2}} e^{\frac{3}{2}}, \tag{28}$$

and the coefficients α and λ by the relations (Part III, No. 41),

$$\alpha = 1 + 2x, \quad \lambda = \frac{2x + x^2}{1 + 2x}. \tag{29}$$

The quantities e, N, and δ for the powders considered are known, and the characteristics having been determined, we may calculate f and w. The following table gives the elements and results of the calculation:

Name of Powder.	e dec.	N	δ	x	α	λ	τ sec.	f	w dec.
A_5B	.128	105	1.810	.631	2.262	.734	.534	424000	.120
A_5S_1, No. 1	.130	116	1.776	.673	2.346	.767	.524	457000	.124
" No. 2	.130	114	1.794	.670	2.340	.765	.537	451000	.121
" No. 3	.130	113	1.805	.670	2.340	.765	.560	442000	.116
" No. 4	.130	107	1.807	.652	2.304	.750	.545	410000	.119
" No. 5	.130	104	1.813	.644	2.228	.739	.846	424000	.076

22. *Calculation of the characteristics of a powder from its physical properties.*—The force of a powder and the velocity of its combustion for a given density depend exclusively upon the process of its

manufacture. If, then, these have been determined for a particular powder, they may be used with any other powder of the same fabrication, however it may differ as to form and dimensions of grain.

When the density of the powder changes, we may calculate the velocity of its combustion approximately by assuming, as indicated by Piobert's experiments, that the velocity varies inversely as the density. We may thus, for all powders of a given fabrication, determine *à priori* the approximate values of f and w. From an examination of the form and dimensions of the grain, the values of τ, a and λ, may then be determined by (27) and (29) of the preceding paragraph.

We have thus all the elements upon which the characteristics depend (9).

22½. *Characteristics of some common powders.*—The following table gives the results of the application of the methods stated to some common powders:

Name of Powder.	N	δ	w dec.	f	e dec.	x	α	λ	τ	a	β
W(20-25)	110	1.800	.0972	431000	.172	1.000	3.000	1.000	.885	1209	1.130
W(16-20)	230	1.775	.0986	431000	.167	1.000	3.000	1.000	.848	1234	1.179
W(13-16)	350	1.750	.1000	431000	.146	1.000	3.000	1.000	.730	1331	1.370
W(10-13)	600	1.715	.1020	431000	.123	1.000	3.000	1.000	.602	1465	1.660
SP_2 . . .	105	1.810	.1200	424000	.128	.631	2.262	.734	.534	1340	1.376
SP_1 . . .	350	1.790	.1213	424000	.100	.792	2.584	.856	.412	1630	2.076
C_2	625	1.760	.1227	424000	.080	.750	2.500	.825	.324	1809	2.545
C_1	1750	1.745	.1245	424000	.065	.916	2.832	.943	.261	2147	3.612

Remarks.—The powders marked W were from the Wetteren factory. The value $f=431000$ is adopted for them; they are described in No. 9.

The velocities of combustion for them are calculated by the formula

$$w=\frac{.1750}{\delta},$$

the constant being so taken as to give for $\delta=1.750$ the value $w=.100$. The grains of the powder W(20-25) are considered as cubes; those of the three others being very irregular, were taken as spheres.

The fabrication of the four other powders in the table is the same as that of the powder A_3B in No. 21. Consequently, the value $f=424000$ was taken for them; and their velocities of combustion were calculated by the formula

$$w=\frac{.2172}{\delta},$$

the constant being so taken as to give for the value $\delta = 1.810$, $w = .120$, corresponding to A_3B. The grains of these powders are considered parallelopipedons with square bases.

23. *Calculation of initial velocities and comparison with the measured results.*—The following table gives the results of this calculation for guns of various calibres, and the corresponding measured velocities:

Name of Gun.	Kind of Powder.	c	u	p Kil.	ϖ	Δ	Velocities. Measured. Meters.	Velocities. Calculated. Meters.	Differences.
32 cent.	W (20-35)	3.220	42.19	352.0	65.	0.786	415.6	414.8	+ 0.8
"	"	"	"	286.5	62.	0.749	451.0	445.7	+ 5.3
"	"	"	"	286.5	61.	0.730	442.5	441.3	+ 1.2
27 cent.	W (20-25)	2.764	40.97	217.0	42.	0.800	431.9	432.0	— 0.1
"	"	"	"	180.0	42.	0.800	470.0	470.3	— 0.3
24 cent.	W (13-16)	2.420	34.45	144.0	28.	0.798	432.0	431.1	+ 0.9
"	"	"	"	Ogival.	24.	0.684	393.2	393.1	+ 0.1
"	"	"	"	"	20.	0.570	352.0	352.4	— 0.4
"	"	"	"	"	16.	0.456	306.6	308.3	— 1.7
"	"	"	"	144.	28.	0.798	428.8	431.1	— 2.3
"	"	"	"	cylindri'l.	24.	0.684	390.5	393.1	— 2.6
"	"	"	"	"	20.	0.570	352.0	352.4	— 0.4
"	"	"	"	"	16.	0.456	303.4	308.3	— 4.9
"	"	"	"	120.	28.	0.798	467.4	469.5	— 2.1
"	"	"	"	"	24.	0.684	427.2	428.1	— 0.9
"	"	"	"	"	20.	0.570	379.5	383.7	— 4.2
"	"	"	"	"	16.	0.456	332.5	335.7	— 3.4
"	"	"	"	96.	28.	0.790	512.5	517.8	— 5.3
"	"	"	"	"	24.	0.684	469.2	472.2	— 3.0
"	"	"	"	"	20.	0.570	420.6	423.2	— 2.7
"	"	"	"	"	16.	0.456	363.0	370.2	— 7.2
"	"	"	38.19	144.	28.	0.789	437.1	437.1	— 7.2
"	"	"	40.36	144.	28.	0.778	434.9	439.0	— 4.1
"	"	"	"	"	24.	0.667	396.6	400.1	— 3.5
"	"	"	"	"	20.	0.556	360.4	358.8	+ 1.6
"	"	"	"	"	16.	0.444	312.3	313.6	— 1.3
19 cent.	"	1.94	30.02	62.5	15.0	0.991	492.2	494.1	— 1.9
"	"	"	"	"	12.5	0.826	444.6	443.0	+ 1.6
"	"	"	"	"	10.0	0.661	393.3	387.5	+ 5.8
"	"	"	"	76.0	15.0	0.991	453.5	454.9	— 1.4
"	"	"	"	"	14.5	0.958	446.4	446.0	+ 0.4
"	"	"	"	"	13.5	0.892	428.7	427.2	+ 1.5
"	"	"	"	"	12.5	0.826	411.8	407.9	+ 3.9
15.5 cent.	SP_1	1.564	24.94	31.8	4.9	0.751	400.2	406.8	— 6.6
"	"	"	"	36.3	4.26	0.653	349.8	351.4	— 1.6
14 cent.	W (13-16)	1.40	26.97	18.65	4.0	0.958	472.0	466.7	+ 5.3
"	"	"	"	"	3.5	0.838	431.2	429.8	+ 1.4
"	"	"	"	"	3.0	0.719	392.0	391.9	+ 0.1
"	"	"	"	23.30	4.0	0.958	428.0	429.3	— 1.3
"	"	"	"	"	3.5	0.838	400.5	396.4	+ 4.1
"	"	"	"	"	3.0	0.719	366.1	361.5	+ 4.6
"	"	"	27.04	21.0	4.0	0.891	438.4	438.4	+ 4.6
13.8 cent.	SP_1	1.390	24.55	23.57	3.8	0.647	400.1	399.6	+ 0.5
"	"	"	"	"	3.46	0.589	377.4	377.8	— 0.4
"	"	"	"	"	2.8	0.477	333.4	332.7	+ 0.7

Name of Gun.	Kind of Powder.	c	u	p Kil.	ϖ	Δ	Velocities. Measured. Meters.	Velocities. Calculated. Meters.	Differences.
12 cent.	SP_1	1.210	19.02	16.32	2.8	0.754	403.3	403.9	— 0.6
"	"	"	"	"	1.74	0.468	299.3	303.6	— 4.3
"	"	"	"	18.25	2.42	0.651	352.2	353.2	— 1.0
"	"	"	"	"	1.85	0.498	296.3	300.6	— 4.3
9.5 cent.	C_2	0.960	23.96	9.13	1.73	0.609	432.1	432.0	+ 0.1
"	"	"	"	8.445	1.63	0.574	426.0	428.5	— 2.5
9 cent.	C_2	0.907	17.98	8.0	1.50	0.888	448.6	447.7	+ 0.9
"	"	"	"	6.5	1.50	0.888	484.7	488.7	— 4.0
"	"	0.911	24.0	8.76	1.60	0.629	426.7	426.4	+ 0.3
"	"	"	"	8.19	1.525	0.597	424.7	427.1	— 2.4
"	"	"	"	7.78	1.47	0.580	422.5	420.3	+ 2.2
"	"	0.909	21.63	10.9	2.40	0.734	448.7	450.6	— 1.9
"	"	"	"	10.9	2.00	0.612	399.0	403.9	— 4.9
"	"	"	"	9.6	2.50	0.765	484.7	492.0	— 7.3
"	"	"	"	9.6	2.22	0.679	449.0	458.1	— 9.1
"	"	"	"	9.6	1.84	0.563	400.4	409.3	— 8.9
"	C_1	0.907	17.98	8.0	1.52	0.899	448.0	453.5	— 5.5
"	"	"	"	8.0	1.40	0.828	434.0	431.7	+ 2.3
"	"	0.9095	18.76	8.0	2.10	0.758	500.6	489.1	+ 11.5
"	"	"	"	8.0	1.94	0.700	475.7	466.5	+ 8.7
8 cent.	"	0.811	16.90	6.0	1.54	0.866	501.0	502.0	— 1.0
"	"	"	"	5.6	1.47	0.826	500.0	505.8	— 5.8
"	"	0.805	19.28	5.5	1.60	0.899	528.6	524.9	+ 3.7
"	"	"	"	5.5	1.40	0.828	484.7	484.5	+ 0.2
7.5 cent.	"	0.750	18.46	5.0	1.250	0.709	484.0	480.0	+ 4.
"	"	"	"	5.0	1.425	0.808	528.0	520.0	+ 8.
"	"	"	"	5.0	1.500	0.850	551.0	546.0	+ 5.
"	"	0.750	15.46	5.0	1.250	0.709	470.0	469.0	+ 1.
"	"	"	"	5.0	1.425	0.808	510.0	508.0	+ 2.
"	"	"	"	5.0	1.500	0.850	529.0	524.0	+ 5.

The preceding table shows that the theoretical formula gives the velocity with very satisfactory exactness in 75 very different conditions of fire in guns whose calibre varies from 320 to 75 millimeters. The mean error for the velocities varying from 300 to 550 meters is less than 3 meters.

It is important to notice that the varying ballistic qualities of the powders of different fabrication taken have doubtless caused some of the discordances in the table.

24. *Fire with the* 16 *cent. gun.*—The following, for example, is a case where the difference between the calculated and measured velocity should, it would appear, be attributed to variations in the qualities of the powder. It is the case of the use of Wetteren powder (13 to 16 mill.) in the 16 cent. gun, model 1870, short.

The principal dimensions of the gun are the following:

Calibre, ... $c = 1.661$

Motion of shot, ... $u = 27.28$

In the following table the calculated and measured velocities will be found. The powder is supposed to have the characteristics of the standard powder.

Name of Gun.	$c.$	$u.$	$p.$	ϖ	Δ	Velocities.		Differences.
						Measured.	Calculated.	
Gun of 16 cent., model 1870.	1.661	27.28	31	5.	0.540	379.4	365.6	+ 13.8
	"	"	"	7.	0.756	467.7	447.4	+ 20.3
	"	"	"	9.	0.972	537.5	520.1	+ 17.4
	"	"	"	9.5	1.026	554.1	537.4	+ 16.7
	"	"	38.25	5.	0.540	351.8	337.9	+ 13.9
	"	"	"	7.	0.756	426.0	413.5	+ 12.5
	"	"	"	9.	0.972	495.0	480.8	+ 14.2
	"	"	"	9.5	1.026	508.3	496.7	+ 11.6
	"	"	45	5.	0.540	326.4	317.1	+ 9.3
	"	"	"	7.	0.756	397.8	388.1	+ 9.7
	"	"	"	9.	0.972	461.8	451.1	+ 10.7
	"	"	"	9.5	1.026	475.2	466.1	+ 9.1

These differences are large, and would throw doubt upon the formula did not the *procès-verbaux* of the experiments show that the powder was different from the standard powder.

In fact, this powder (taken from the lot number 15) gave to the 24 and 14 cent. guns in the conditions specified in No. 9, velocities respectively of 435 and 456 meters, instead of 437 and 438, which were those given by the standard powder.

The characteristics of lot No. 15 deduced from the velocities by the method of No. 19 are

$$\alpha = 1429, \ \beta = 1.570;$$

these differ considerably from those of the standard powder, which are

$$\alpha = 1331, \ \beta = 1.370.$$

These new values have been used in the calculation of the velocities in the following table, whose accuracy is very satisfactory.

Name of Gun.	c	u	p	ϖ	Δ	Velocities.		Differences.
						Measured.	Calculated.	
Gun of 16 cent., model 1870.	1.661	27.28	31.	5.	0.540	379.4	379.0	+ 0.4
	"	"	"	7.	0.756	467.7	463.8	+ 3.9
	"	"	"	9.	0.972	537.5	539.1	— 1.6
	"	"	"	9.5	1.026	554.1	557.1	— 3.0
	"	"	38.25	5.	0.540	351.8	348.6	+ 3.2
	"	"	"	7.	0.756	426.0	426.6	— 0.6
	"	"	"	9.	0.972	495.0	495.9	— 0.9
	"	"	"	9.5	1.026	508.3	512.4	— 4.1
	"	"	45.	5.	0.540	326.4	325.6	+ 0.8
	"	"	"	7.	0.756	397.8	398.4	— 0.6
	"	"	"	9.	0.972	461.8	463.2	— 1.4
	"	"	"	9.5	1.026	475.2	478.5	— 3.3

25. It will be interesting to ascertain the nature of the change undergone by this powder; the considerations set forth in No. 21 will enable us to do this. If, by (26), we derive from the values of the characteristics those of the force and time of combustion, we find for the powder considered,

$$f=433000, \quad \tau=0.637.$$

For the standard powder we have

$$f=431000, \quad \tau=0.730.$$

The values of f do not differ sensibly, but the values of τ do. The velocity of combustion has therefore been altered by some circumstance of fabrication.

26. *Calculation of pressures.*—The following are applications of (22) to the calculation of the maximum pressure; this requires that α shall be known.

This element having been determined by the five lots of A_3S powder considered in No. 19, we may calculate the pressure produced by this powder in the 24 centimeter gun in the ordinary conditions; and, as these pressures have generally been measured by *manomètres à écrasement*, the calculated results may be compared with these. The following table contains the data and results:

Name of Powder.	c	p	ϖ	Δ	Measured. Velocities.	Pressures. Measured.	Calculated.
A_3S' No. 1	2.42	144	28	0.789	453.8	2790	2680
" No. 2	"	"	"	"	451.0	2480	2570
" No. 3	"	"	"	"	446.7	2330	2420
" No. 4	"	"	"	"	431.1	2010	2250
" No. 5	"	"	"	"	412.2	1440	1470

The agreement of the calculated and measured pressures is not so close as in the case of the velocities; but it must be remembered that the instruments with which the pressures are measured are not accurate. In fact, it is evident, from the preceding table, that the formula represents, generally, the variations of pressure with an accuracy which, if it is always maintained, is sufficient for practical purposes. This last point can only be satisfactorily determined when the measurements of internal pressures shall be more varied and more numerous than at present.

27. We resume in the following table the results of calculation in some of the conditions of fire which form the object of No. 19.

The conditions are those which, for each gun, correspond to the greatest simultaneous values of the weights of projectile and charge.

Name of Gun.		Name of Powder.	c	u	p	ϖ	Δ	Observed velocity.	Calculated pressure.
32	cent.	W(20-25)	3.220	42.19	352.	65.	0.786	415.6	2560
27	"	"	2.764	40.97	217.	42.	0.800	431.9	2240
24	"	W(13-16)	2.420	38.19	144.	28.	0.789	437.1	2320
19	"	"	1.940	30.02	76.	15.	0.991	454.9	2410
15.5	"	SP_1 . .	1.564	24.94	36.3	4.26	0.653	349.8	1350
14	"	W(13-16)	1.400	26.97	23.3	4.	0.958	428.0	1280
13.8	"	SP_1 . .	1.390	24.55	23.57	3.80	0.647	400.1	1300
12	"	" . . .	1.210	19.025	18.25	2.42	0.651	352.2	1200
9.5	"	C_2 . . .	0.960	23.96	9.13	1.73	0.609	432.1	1320
9	"	" . . .	0.907	17.98	8.	1.50	0.888	448.6	1870
9	"	" . . .	0.911	24.00	8.76	1.60	0.629	426.7	1420
9	"	" . . .	0.909	21.63	10.90	2.40	0.734	448.7	2280
9	"	C_1 . . .	0.907	17.98	8.	1.52	0.899	448.0	2680
9	"	" . . .	0.9095	18.76	8.	2.10	0.758	500.6	2650
8	"	" . . .	0.811	16.90	6.	1.54	0.866	501.0	2820
8	"	" . . .	0.805	19.28	5.50	1.60	0.899	528.6	2900
7.5	"	" . . .	0.750	18.46	5.	1.50	0.850	551.0	2920

CHAPTER III.

I.—MAXIMUM OF VELOCITIES.

28. In Art. 6 the initial velocity is given as a function of the elements of firing by the formula:

$$v = A\left(\frac{fa}{\tau}\right)^{\frac{1}{2}}\left(\frac{\varpi}{p}\right)^{\frac{1}{4}}\left(\frac{\varpi}{c^2}\right)^{\frac{1}{10}}\Delta^{\frac{1}{4}}u^{\frac{4}{10}}\left[1 - B\,\frac{\lambda}{\tau}\,\frac{(pu)^{\frac{1}{2}}}{c}\right],$$

A and B being two constants. The signification of the other letters is that given in Articles 2, 5, and 7 of the first Chapter. Now if in this formula we make τ a variable, all the other elements being constant, the velocity will pass through a maximum.

29. Put for brevity:

$$\varphi(\tau) = \tau^{-\frac{1}{2}} - B\,\frac{\lambda(pu)^{\frac{1}{2}}}{c}\,\tau^{-\frac{3}{2}} \tag{30}$$

and we have:

$$v = A(fa)^{\frac{1}{2}}\left(\frac{\varpi}{p}\right)^{\frac{1}{4}}\left(\frac{\varpi}{c^2}\right)^{\frac{1}{10}}\Delta^{\frac{1}{4}}u^{\frac{4}{10}}\varphi(\tau). \tag{31}$$

The value of τ corresponding to the maximum of φ, and therefore of v, is given by the condition $\varphi'(\tau) = 0$, that is to say, by the relation,

$$(32) \qquad B\frac{\lambda(pu)^{\frac{1}{2}}}{\tau c} = \frac{1}{3},$$

denoting that value by τ_1 we have

$$(33) \qquad \tau_1 = 3B\frac{\lambda(pu)^{\frac{1}{2}}}{c}.$$

The corresponding velocity is then deduced from the relation

$$(34) \qquad v_1 = \frac{2}{3}A\left(\frac{fa}{\tau_1}\right)^{\frac{1}{2}}\left(\frac{\varpi}{p}\right)^{\frac{1}{4}}\left(\frac{\varpi}{c^2}\right)^{\frac{1}{10}}\Delta^{\frac{1}{4}}u^{\frac{4}{10}},$$

or better still, replacing τ_1 by its value (33),

$$(35) \qquad v_1 = A_1\left(\frac{fa}{\lambda}\right)^{\frac{1}{2}}\frac{\varpi^{\frac{7}{20}}c^{\frac{3}{10}}\Delta^{\frac{1}{4}}u^{\frac{3}{20}}}{p^{\frac{1}{2}}},$$

the value of A_1 being (1)

$$A_1 = \frac{2}{3}A(3B)^{-\frac{1}{2}}.$$

30. The consideration of the theoretical maximum permits us to express the formula for velocities in another form. For a powder nearly like the maximum let

$$\tau = \tau_1 + \theta.$$

We have for the corresponding value of the function $\varphi(\tau)$:

$$\varphi(\tau) = \varphi(\tau_1 + \theta) = \varphi(\tau_1)\theta + \varphi'(\tau_1)\theta + \varphi''(\tau_1)\frac{\theta^2}{2} + \ldots$$

or simply:

$$\varphi(\tau) = \varphi(\tau_1) + \varphi''(\tau_1)\frac{\theta^2}{2},$$

taking into account the condition $\varphi'(\tau_1) = 0$ and neglecting terms of an order greater than the second.

This being granted, we find from formula (30):

$$\varphi''(\tau) = \frac{3}{4}\tau^{-\frac{5}{2}}\left[1 - 5B\frac{\lambda(pu)^{\frac{1}{2}}}{\tau c}\right].$$

Replacing τ by τ_1 and taking into account the condition (32) which is then satisfied, it becomes:

$$\varphi''(\tau_1) = -\frac{1}{2}\tau_1^{-\frac{5}{2}}.$$

Under the same hypothesis, formula (30) gives

$$\varphi(\tau_1) = \frac{2}{3}\tau_1^{-\frac{1}{2}}.$$

We can then write: $\varphi''(\tau_1) = -\frac{3}{4} \cdot \frac{\varphi(\tau_1)}{\tau_1^2}$, and consequently

$$\varphi(\tau) = \varphi(\tau_1)\left[1 - \frac{3}{4}\frac{\theta^2}{\tau_1^2}\right],$$

whence the formula for velocities:

$$v = v_1\left[1 - \frac{3}{4}\frac{\theta^2}{\tau_1^2}\right]. \quad (36)$$

v_1 and τ_1 being the values of (35) and (33). Formula (36) shows that the velocity is very little modified when τ varies in the neighborhood of the value of the maximum. If, for example, we suppose $\frac{\theta}{\tau_1} = 0.2$, that is to say, if the difference between τ and τ_1 is $\frac{1}{5}$ of the value of τ_1, the corresponding difference between the velocities v and v_1 is only $\frac{3}{100}$ of the value of v_1.

32. *Ballistic coefficient.*—It results from formula (35) that for given values of the various elements of firing, the greatest velocity that a powder can produce is proportional to $\left(\frac{fa}{\lambda}\right)^{\frac{1}{2}}$. This factor, which has been called the *ballistic coefficient*, depends at the same time on the force of the powder and the form of the grain.

If the force is constant the ballistic coefficient is proportional to $\left(\frac{a}{\lambda}\right)^{\frac{1}{2}}$. It depends only on the form of the grain.

When the grain is spherical or cubical we have $a = 3$ and $\lambda = 1$. If then we designate by C the ballistic coefficient of a powder referred to that of a spherical or cubical powder of the same force, we can put:

$$C = \left(\frac{a}{3\lambda}\right)^{\frac{1}{2}}.$$

The value of C is greater than 1 for grains of the form of a parallelopipedon or a pierced cylinder. We can, then, by the employment of these grains, increase the velocity without changing the other elements of firing. But in practice this increase cannot pass a certain limit on account of the corresponding increase of the maximum pressure, which varies as the square of the ballistic coefficient, and rapidly approaches the limit imposed by the resistance of the piece.

33. Several experimental facts, notably those of Maguin, demonstrate that there exists for each gun and in each condition of firing, a size of grain and consequently a duration of combustion of the grain, which gives a maximum of velocity.

It remains to verify if this maximum is shown in the conditions indicated by theory. The following is a case in which theory and experiment seem to be in accord.

If we consider the firing of a 24 cent. gun under the habitual conditions of proof, and if we calculate the value of τ which for a spherical or cubical grain correspond to the maximum, making in formula (33) $\lambda = 1$, $c = 2.42$, $u = 38.19$, $p = 144$, we find

$$\tau_1 = 0.731,$$

a value exactly equal to that given in the table of No. 22 for the standard powder. Wetteren powder (grains of 13 to 16 mill.) is then the maximum for the 24 cent. gun. This result seems confirmed by experiment, since the sample No. 15 duration of combustion 0.637, and less than that of the standard powder, gave only 435 meters initial velocity as compared to 437 meters given by the standard powder.

34. It would be an advantage to adopt a maximum powder, not only because the charge would thus be better utilized, but also for the reason that the chance variations which are made in the manufacture of the powder, affecting the velocity of combustion, would not have a sensible influence on the initial velocity, which assures regularity of fire.

This remark explains the relatively small differences shown in the proof of samples of powder for the 24 cent. gun. The differences should be more marked in the case of the 14 cent. gun, for which the maximum powder is very different from the standard powder of 13 to 16 millimeters. (In the case of the 14 cent. gun, we have $\lambda = 1$, $C = 1.40$, $u = 27.04$, $p = 21$; the corresponding value of τ_1, calculated by formula (33), is

$$\tau_1 = 0.406.$$

It should be remarked, however, that the employment of a maximum powder gives generally very high interior pressures, and this inconvenience is also more serious since irregularities in the fabrication can in this case produce great variations of pressure without sensibly modifying the velocity. This particularity is found from the special form of the functions which represent the velocity and the maximum pressure. The velocity is the difference of two terms increasing together as τ diminishes, so that their variations compensate near the maximum. The pressure is represented, however, by a monomial

formula, and it varies rapidly in the inverse ratio of the period of combustion.

Example: The sample of Wetteren powder No. 15 already cited gives, in the 24 cent. gun, 435 meters initial velocity. The initial velocity given by the standard powder is 437 meters. The calculated corresponding pressures are 2660 kil. for sample No. 15, and 2330 kil. for the standard powder.

Sample No. 15 is then notably more violent than the standard powder, and also the initial velocity given is a little less.

II.—Maximum of Living Force.

35. When we increase the mass m of the projectile, the other elements remaining constant, the velocity v diminishes in such a manner that the living force mv^2 increases in general. Experiment indicates, however, that this augmentation is not indefinite, and that the living force attains a maximum.

This remarkable fact, which M. Navez was the first to assert, does not accord with ballistic formulæ generally used. It is, however, very well explained by the theoretical formula. This formula indicates, in fact, that the product of the velocity by the square root of the weight of the projectile passes through a maximum.

Put for brevity

$$\psi(p) = p^{\frac{1}{4}} - B\frac{\lambda u^{\frac{1}{2}}}{\tau c} p^{\frac{3}{4}}. \tag{37}$$

We have from the formula for velocities

$$p^{\frac{1}{2}} v = A\left(\frac{fa}{\tau}\right)^{\frac{1}{2}} \varpi^{\frac{1}{4}} \left(\frac{\varpi}{c^2}\right)^{\frac{1}{10}} \varDelta^{\frac{1}{4}} u^{\frac{4}{10}} \psi(p). \tag{38}$$

The maximum of this expression, since p varies, corresponds to the maximum of ψ, and is given by the condition $\psi'(p) = 0$, that is to say, in making the calculation by the relation

$$B\frac{\lambda (pu)^{\frac{1}{2}}}{\tau c} = \frac{1}{3}.$$

This relation is the same as (32), which we have found to be the relation expressing the duration of the combustion of a grain which gives a maximum velocity.

Consequently, in establishing this relation between the quantities λ, τ, p, u and c, we make a maximum :

1st. The velocity of the projectile with respect to the variations of the duration of combustion of the powder.

2d. The living force of the projectile with respect to the variations of its weight. This relation is satisfied, according to No. 33, in the firing of Wetteren standard powder (grains of 13 to 16 mill.) in the 24 centimeter gun with a projectile of 144 kilograms.

The result is, on account of the relations adopted, the projectile weighing 144 kilograms corresponds to the maximum for useful effect.

III.—Influence of the Various Elements of Firing on Velocity and Pressure.

36. In a cannon we may consider the quantities

$$c, u, p,$$

(calibre, length of path, and weight of projectile) as constant or given quantities. The variables with which in connection with the constant quantities we wish to obtain a given velocity, are

$$f, a, \lambda, \tau, \varpi, \Delta,$$

and there may be an infinite number of combinations made with these variables giving the same velocity with different maximum pressures or the same pressure with different velocities.

It has been shown (Part III, Art. 57) how we can, with fixed values of ϖ and Δ, lower the pressure and retain the velocity, or increase the velocity and retain the same pressure by a proper choice of the variables,

$$f, a, \lambda, \tau,$$

which refer exclusively to the powder.

37. We may consider as known also f, a, λ, that is to say, the force of the powder and the form of the grain, and evaluate the influence of ϖ, Δ, and τ on the values of the velocity and maximum pressure. With this in view, consider formula (31) for velocities. The factor $\varphi(\tau)$ is given by equation (30), which we may write, taking into account equation (33), in an abbreviated form, thus:

$$\varphi(\tau) = \frac{3\tau - \tau_1}{3\tau^{\frac{3}{2}}}, \tag{39}$$

τ_1 being the value of τ corresponding to the maximum velocity with the form of grain adopted.

If, then, we suppose the quantities ϖ, Δ and τ to be the only variables, we may put

$$v = K\varpi^{\frac{7}{20}}\Delta^{\frac{1}{4}}\tau^{-\frac{3}{2}}(3\tau - \tau_1),$$

K denoting a constant. The corresponding value of the maximum pressure is, according to equation (18):

$$P = K' \frac{\varpi^{\frac{1}{2}} \Delta}{\tau}.$$

38. We wish to find the variation of v and P for very small increments $d\varpi$, $d\Delta$, $d\tau$, of the variables. We find very easily:

$$(40) \qquad \frac{dv}{v} = \frac{7}{20} \frac{d\varpi}{\varpi} + \frac{1}{4} \frac{d\Delta}{\Delta} - \frac{3}{2} \frac{\tau - \tau_1}{3\tau - \tau_1} \cdot \frac{d\tau}{\tau},$$

$$(41) \qquad \frac{dP}{P} = \frac{1}{2} \cdot \frac{d\varpi}{\varpi} + \frac{d\Delta}{\Delta} - \frac{d\tau}{\tau}.$$

The influence of each variable on the value of the velocity is measured by the coefficient which multiplies the relative variation of each variable in expression (40).

The coefficients of $\frac{d\varpi}{\varpi}$, $\frac{d\Delta}{\Delta}$, and $\frac{d\tau}{\tau}$ are respectively:

$$\frac{7}{20}, \ \frac{1}{4}, \ \frac{3}{2} \cdot \frac{\tau - \tau_1}{3\tau - \tau_1}.$$

The third coefficient varies with τ and is equal to zero for $\tau = \tau_1$.

Its value increases with τ, but does not exceed $\frac{1}{4}$ except where τ is greater than $\frac{5}{3}\tau_1$, which is not likely to happen in the habitual conditions of practice.

39. It follows from the preceding that the three coefficients are arranged in the order of their relative value, and that the variations of each of the variables

$$\varpi, \ \Delta, \ \tau$$

have more influence than the one next on its right as arranged above.

On the contrary, the influence of ϖ on the maximum pressure is less than that of Δ or τ.

40. The following tables show, in a particular case, the theoretical values and pressures corresponding to the various values of the elements of firing.

The results show better than can be done by an analytical formula the proper influences of these elements on the effects obtained. These calculations relate to a Krupp gun, calibre 30 centimeters.

The data for this gun may be stated as follows:

Calibre, ...	$C = 3.05$ decimeters
Length of path of projectile .	$u = 44.60$ "
Weight of projectile	$p = 300$ kilograms.

The variables at our disposal are as follows:

f force of the powder,

a, λ characteristics of the form of the grain,

τ duration of the combustion of a grain,

ϖ weight of the charge,

$\varDelta$ density of loading.

We shall vary them according to the following conditions:

1st. f.—The value of f depends on the composition of the powder and manner of manufacture. We shall adopt the value $f = 424000$, which according to the table of No. 22 is the value for powders of French manufacture.

2d. a, λ.—We will consider three forms of grains—

(A). Cubical or spherical.

(B). Parallelopipedon with square base, the side of the base double the thickness.

(C). Cylinder pierced, the height double the thickness.

The corresponding values of a and λ are the following:

Form of grain.	Values of a	Values of λ
Cubical or Spherical, ...	3	1
Parallelopipedon, ...	2	$\frac{5}{8}$
Cylinder, pierced, ...	$\frac{3}{2}$	$\frac{1}{3}$

3d. τ.—We shall vary τ, by intervals of $\frac{1}{10}$ of a second, starting from particular values which, for the three forms of grain, correspond to the maximum velocity.

These values are calculated by formula (33) with the data c, u, p, shown above.

Form of grain.	Values of τ_1.
Cube or Sphere, ...	0.904
Parallelopipedon, ...	0.565
Pierced Cylinder, ...	0.301

4th. ϖ.—The values given to the weight ϖ of the charge are $\frac{1}{6}$, $\frac{1}{5}$, $\frac{1}{4}$, of the weight of the projectile, or 50, 60, 75 kilograms.

5th. $\varDelta$.—Finally, we will consider the values of the density of loading,

1.0 0.9 0.8 0.7

The calculation of velocities and pressures is done without difficulty by the aid of formulæ (15) and (22), in which we recall that the characteristics α, β are respectively

$$\alpha = \left(\frac{fa}{\tau}\right)^{\frac{1}{2}}, \quad \beta = \frac{\lambda}{\tau}.$$

We have not given in the table velocities greater than 550 meters.

The discussion of the preceding gives rise to some interesting remarks, which may be generalized by remembering the principle of similitude established in a preceding work; but the greater part of the results thus obtained may be deduced with more simplicity and precision from formulæ which will be made the object of a subsequent number. We will therefore abstain from an extensive development of this subject, confining ourselves to the following observations. According to data given by the *Revue d'Artillerie*, the 30.5 cent. Krupp gun has given an initial velocity of 460 meters with a charge of $\frac{1}{5}$ the weight of the projectile, that is, 60 kilograms of prismatic powder, of 25 millimeters.

Now from an examination of the table:

1st. This velocity is impossible, under these conditions, with a powder composed of cubical or spherical grains.

2d. That it may be realized by a powder, grains of the form of a parallelopipedon, with a pressure of nearly 2700 kilograms, a result not assuring, considering the strength of the piece.

3d. That it may be easily obtained with much less pressure, by the use of the pierced cylindrical grain.

We have, for example, a velocity of 460 meters and a pressure of 1800 kilograms very nearly by taking $\Delta = 0.7$ and τ between 0.5 and 0.6. It is easy then to fix the approximate dimensions of the grain. Supposing $\tau = 0.55$, and giving to the powder material a velocity of combustion of 12 millimeters a second, we see that the thickness of the grain would be regulated by the equation $\frac{\varepsilon}{2} = 12 \times 0.55$, whence $\varepsilon = 13.2$ millimeters. The height being double the thickness is then 26.4 millimeters, which seems to accord well with the solution adopted by the German artillery.

CHAPTER IV.

On the greatest Value of the Velocity corresponding to a given Value of the Maximum Pressure.

42. Suppose, for a gun, we make all the elements of firing constant with the exception of the density of loading Δ and the duration of combustion τ, which we consider variable.

We have not given in the table velocities greater than 550 meters.

The discussion of the preceding gives rise to some interesting remarks, which may be generalized by remembering the principle of similitude established in a preceding work; but the greater part of the results thus obtained may be deduced with more simplicity and precision from formulæ which will be made the object of a subsequent number. We will therefore abstain from an extensive development of this subject, confining ourselves to the following observations. According to data given by the *Revue d'Artillerie*, the 30.5 cent. Krupp gun has given an initial velocity of 460 meters with a charge of $\frac{1}{5}$ the weight of the projectile, that is, 60 kilograms of prismatic powder, of 25 millimeters.

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TABLE I.—Cubical or Spherical Grain.

$(a = 3,\ \lambda = 1.)$

Values of τ.	Charge of $\frac{1}{6}$ ($\varpi = 50$ Kilos.)								Charge of $\frac{1}{5}$ ($\varpi = 60$ Kilos.)								Charge of $\frac{1}{4}$ ($\varpi = 75$ Kilos.)							
	$\Delta = 1$		0.9		0.8		0.7		$\Delta = 1$		0.9		0.8		0.7		$\Delta = 1.0$		0.9		0.8		0.7	
	v	P	v	P	v	P	v	P	v	P	v	P	v	P	v	P	v	P	v	P	v	P	v	P
0.904	428.2	2835	417.0	2252	404.9	2268	391.7	1985	456.4	3105	444.1	2794	431.6	2485	417.4	2174	493.5	3471	480.7	3124	466.8	2777	451.4	2430
1.000	426.6	2563	415.4	2306	403.5	2050	390.2	1780	454.7	2807	442.8	2526	430.0	2245	416.0	1950	491.7	3134	478.9	2823	465.1	2510	449.8	2196
1.10	422.7	2330	411.6	2097	399.8	1864	386.6	1631	450.5	2552	438.7	2296	426.1	2041	412.1	1786	487.2	2852	474.5	2567	460.8	2282	445.7	1997
1.20	417.4	2136	406.5	1922	394.7	1709	381.8	1495	444.8	2339	433.2	2105	420.7	1871	406.9	1637	481.1	2614	468.5	2353	455.0	2092	440.1	1830
1.30	411.2	1971	400.4	1775	388.9	1577	376.1	1380	438.2	2159	426.8	1943	414.5	1728	400.9	1512	473.9	2414	461.5	2172	448.2	1931	433.6	1690
1.40	405.1	1831	394.5	1648	383.1	1464	370.5	1281	431.7	2005	420.4	1804	408.3	1604	394.9	1403	466.9	2241	454.7	2017	441.6	1793	427.1	1569
1.50	397.9	1708	387.5	1537	376.4	1367	364.0	1196	424.1	1871	413.1	1684	401.1	1497	388.0	1310	458.7	1092	446.7	1882	433.8	1673	419.6	1464

TABLE II.—Parallelopipedon with Square Base.

$(x = \frac{1}{2},\ a = 2,\ \lambda = \frac{3}{8}.)$

Values of τ.	Charge of $\frac{1}{6}$ ($\varpi = 50$ Kilos.)								Charge of $\frac{1}{5}$ ($\varpi = 60$ Kilos.)								Charge of $\frac{1}{4}$ ($\varpi = 75$ Kilos.)							
	$\Delta = 1.$		0.9		0.8		0.7		$\Delta = 1$		0.9		0.8		0.7		$\Delta = 1$		0.9		0.8		0.7	
	v	P	v	P	v	P	v	P	v	P	v	P	v	P	v	P	v	P	v	P	v	P	v	P
0.565	442.2	3024	430.6	2722	418.2	2419	404.5	2117	471.3	3565	459.0	2981	445.8	2650	431.1	2318	509.7	3703	496.4	3332	482.1	2962	466.2	2592
0.6	441.6	2847	430.0	2562	417.6	2278	403.9	1993	470.7	3118	458.4	2806	445.2	2495	430.6	2183	509.0	3486	495.7	3137	481.4	2789	465.6	2440
0.7	435.6	2441	424.2	2196	412.0	1953	398.5	1708	464.3	2673	452.2	2405	439.1	2138	424.7	1871	502.1	2988	489.0	2689	474.9	2391	459.3	2092
0.8	426.2	2135	415.1	1922	403.1	1708	389.9	1495	454.3	2339	442.4	2105	429.6	1871	415.5	1637	491.2	2615	478.4	2353	464.6	2092	449.4	1830
0.9	415.5	1943	404.7	1748	393.0	1554	380.1	1360	442.9	2128	431.3	1915	418.9	1702	405.1	1490	479.0	2379	466.5	2141	453.0	1903	438.1	1665
1.0	404.7	1708	394.1	1538	382.8	1367	370.2	1196	431.3	1871	420.1	1684	408.0	1497	394.6	1310	466.5	2091	454.3	1882	441.2	1673	426.7	1474

TABLE III.—Pierced Cylinder.

$(x = \frac{1}{2},\ a = 2,\ \lambda = \frac{1}{3}.)$

Values of τ.	Charge of $\frac{1}{6}$ ($\varpi = 50$ Kilos.)								Charge of $\frac{1}{5}$ ($\varpi = 60$ Kilos.)								Charge of $\frac{1}{4}$ ($\varpi = 75$ Kilos.)							
	$\Delta = 1$		0.9		0.8		0.7		$\Delta = 1$		0.9		0.8		0.7		$\Delta = 1$		0.9		0.8		0.7	
	v	P	v	P	v	P	v	P	v	P	v	P	v	P	v	P	v	P	v	P	v	P	v	P
0.301	524.5	4254	510.7	3828	496.0	3403	480.0	2978	......	......	544.4	4193	528.7	3727	511.3	3261	......	......	......	......	......	......	......	......
0.400	511.2	3203	497.8	2883	483.5	2562	467.6	2242	544.9	3508	530.7	3157	515.4	2807	498.4	2456	......	......	......	......	......	......	539.0	2745
0.500	488.0	2562	475.2	2306	461.5	2050	446.4	1794	520.1	2807	506.5	2526	491.9	2245	475.8	1965	......	......	547.8	2823	532.0	2510	514.5	2196
0.600	464.0	2135	451.9	1922	438.9	1708	424.4	1495	494.5	2339	481.6	2105	467.8	1871	452.4	1637	534.8	2615	520.8	2353	505.0	2092	489.2	1830
0.700	442.1	1830	430.5	1647	418.1	1464	404.4	1311	471.2	1996	458.9	1804	445.7	1604	431.0	1404	509.6	2241	496.3	2017	482.8	1793	466.2	1569
0.800	422.0	1602	411.0	1441	399.1	1281	386.0	1121	449.8	1754	438.0	1579	425.4	1403	411.4	1228	486.4	1961	473.7	1765	460.1	1569	444.9	1373
0.900	404.4	1424	393.8	1281	382.5	1139	378.5	1000	431.0	1559	419.8	1404	407.7	1248	403.5	1091	466.1	1744	454.0	1569	440.9	1395	426.4	1220
1.000	388.3	1281	378.2	1153	367.3	1025	355.2	897	413.9	1403	403.1	1263	391.5	1123	378.6	983	447.6	1569	435.9	1412	423.3	1255	409.5	1098

We can deduce from the theoretical formulæ the following result: *Among the systems of values of Δ and τ which give the same pressure there is one for which the velocity is a maximum.*

To demonstrate it, consider formulæ (31) and (18) for velocities and pressures; putting for brevity:

$$(42)\qquad H = A(fa)^{\frac{1}{2}}\left(\frac{\varpi}{p}\right)^{\frac{1}{4}}\left(\frac{\varpi}{c^2}\right)^{\frac{1}{10}}u^{\frac{4}{10}},$$

$$(43)\qquad h = K\frac{fa\,(p\varpi)^{\frac{1}{2}}}{c^2}.$$

These formulæ may be written under the form:

$$(44)\qquad v = H\Delta^{\frac{1}{4}}\varphi(\tau),$$

$$(45)\qquad P = \frac{h\Delta}{\tau},$$

in which the variables Δ and τ are the principal quantities to consider.

Eliminating Δ between (44) and (45) we have

$$v = Hh^{-\frac{1}{4}}\tau^{-\frac{1}{4}}\varphi(\tau)P^{\frac{1}{4}},$$

whence taking account of (39) the value of $\varphi(\tau)$:

$$(46)\qquad v = \frac{1}{3}Hh^{-\frac{1}{4}}\tau^{-\frac{5}{4}}(3\tau - \tau_1)P^{\frac{1}{4}}.$$

For a given value of P this value of v depends only on the variable τ and it passes through a maximum for the particular value

$$(47)\qquad \tau_0 = \frac{5}{3}\tau.$$

The corresponding values of the density of loading and of the velocity deduced from relations (45) and (46) are:

$$(48)\qquad \Delta_0 = \frac{5}{3}\frac{\tau_1 P}{h},$$

$$(49)\qquad v_0 = \frac{4}{3}\left(\frac{3}{5}\right)^{\frac{5}{4}}H(h\tau_1)^{-\frac{1}{4}}P^{\frac{1}{4}}.$$

43. Replacing τ, H, and h in (47), (48) and (49) by their values (33), (42) and (43), we have

$$(50)\qquad \tau_0 = 5B\frac{\lambda(pu)^{\frac{1}{2}}}{c},$$

$$(51)\qquad \Delta_0 = \frac{5B}{K}\cdot\frac{\lambda c u^{\frac{1}{2}}}{fa\varpi^{\frac{1}{2}}}P,$$

$$(52)\qquad v_0 = \frac{4}{3}\left(\frac{3}{5}\right)^{\frac{5}{4}}\cdot\frac{A}{(3BK)^{\frac{1}{4}}}\cdot\left(\frac{fa}{\lambda}\right)^{\frac{1}{4}}\cdot\frac{\varpi^{\frac{9}{40}}u^{\frac{11}{40}}c^{\frac{11}{20}}}{p^{\frac{1}{2}}}P^{\frac{1}{4}},$$

or better, taking account of the numerical values of A, B, K (we have from (14) of Art. 10, $A = 1.569$, $B = 0.00795$, and from formula (22) of Art. 14 $K = 0.0153$),

$$\tau_0 = 0.02875 \frac{\lambda (pu)^{\frac{1}{2}}}{c}, \tag{53}$$

$$\Delta_0 = 2.598 \frac{\lambda c u^{\frac{1}{2}}}{f a \varpi^{\frac{1}{2}}} P, \tag{54}$$

$$v_0 = 7.993 \left(\frac{fa}{\lambda}\right)^{\frac{1}{4}} \cdot \frac{\varpi^{\frac{9}{40}} u^{\frac{11}{40}} c^{\frac{11}{20}}}{p^{\frac{1}{2}}} P^{\frac{1}{4}}. \tag{55}$$

44. In the greater number of cases, notably when the value of P is considerable, formula (54) gives for the density of loading values which cannot be attained in practice. The greatest value possible of v is obtained by taking Δ equal to its limiting value.

If we suppose this value to be unity, the corresponding value of τ is found from equation (45), which, making $\Delta = 1$, and replacing h by its value from (43), gives

$$\tau = K \frac{fa(p\varpi)^{\frac{1}{2}}}{c^2} \cdot \frac{1}{P}. \tag{56}$$

Under the same hypothesis, formula (8) gives for the velocity:

$$v = \frac{A}{K^{\frac{1}{2}}} \cdot \frac{\varpi^{\frac{1}{10}} u^{\frac{4}{10}} c^{\frac{8}{10}}}{p^{\frac{1}{2}}} \left[1 - \frac{B}{H} \cdot \frac{\lambda c u^{\frac{1}{2}}}{f a \varpi^{\frac{1}{2}}} P\right] P^{\frac{1}{2}}. \tag{57}$$

We may remark that in this expression the quantity between brackets is equal, according to equation (51), to $\frac{1}{5}\Delta_0$; taking this into account and replacing the coefficients K and A in (57) and (56) by their numerical values, we have the following system:

$$\tau = 0.0153 \frac{fa(p\varpi)^{\frac{1}{2}}}{c^2} \cdot \frac{1}{P}, \tag{58}$$

$$\Delta = 1, \tag{59}$$

$$v = 12.7 \frac{\varpi^{\frac{1}{10}} c^{\frac{8}{10}} u^{\frac{4}{10}}}{p^{\frac{1}{2}}} \left[1 - \frac{1}{5}\Delta_0\right] P^{\frac{1}{2}}; \tag{60}$$

which should be substituted for formulæ (53), (54) and (55) when the elements of firing are such that the value of Δ_0 (54) is greater than unity.

45. In attributing to P the limiting value which it cannot pass without compromising the safety of the piece, the above formulæ serve to calculate the greatest velocity that can be realized in a given piece, with a given form of grain, and given weights of the projectile and charge.

To this end, we calculate first the value of Δ_0 from (54).

If this value is less than 1 we adopt it for the density of loading and calculate the duration of combustion by formula (53). If, however, the deduced value of Δ is greater than 1, we take the density of loading equal to 1, and calculate the duration of combustion by formula (58).

The velocity sought is given by formula (55) in the first case and by formula (60) in the second case.

46. We give some applications of these calculations to the 30 centimeter Krupp gun.

1st. Suppose first the limit of P is fixed at 2500 kilograms per square centimeter, then with the units adopted $P = 250000$.

The values of Δ_0 for the three forms of grain already considered, and of charges of $\frac{1}{6}$, $\frac{1}{5}$, and $\frac{1}{4}$ the weight of the projectile, are summarized in the following table:

Designation of the form of the grain.	Δ_0 Values of ϖ 50 Kilos.	60 Kilos.	75 Kilos.
Cube,	1.471	1.342	1.201
Parallelopipedon,	1.379	1.259	1.126
Pierced cylinder,	0.980	0.895	0.800

The following table gives the corresponding values of τ, Δ, and the velocity v.

Designation of the form of grain.	$\varpi = 50$ Kilos.			$\varpi = 60$ Kilos.			$\varpi = 75$ Kilos.		
	τ	Δ	v	τ	Δ	v	τ	Δ	v
Cube,	1.025	1.000	426.0	1.123	1.000	449.7	1.255	1.000	477.5
Parallelopipedon,	0.683	1.000	437.6	0.749	1.000	460.4	0.837	1.000	487.4
Pierced cylinder,	0.490	0.980	485.5	0.490	0.895	505.8	0.490	0.800	531.9

2d. Suppose in the second place the limit of P reduced to 1500 kilograms per square centimeter, which corresponds very nearly to the strength of bronze pieces.

Making $P = 150000$, formula (54) gives the values of Δ_0 less than unity; which are adopted as the densities of loading, and v and τ are calculated from formulæ (55) and (53).

We thus obtain the following table:

Designation of form of grain.	$\varpi = 50$ Kilos.			$\varpi = 60$ Kilos.			$\varpi = 75$ Kilos.		
	τ	Δ	v	τ	Δ	v	τ	Δ	v
Cube,	1.469	0.882	386.1	1.469	0.805	402.3	1.469	0.720	423.0
Parallelopipedon,	0.918	0.827	392.4	0.918	0.755	408.8	0.918	0.675	429.8
Pierced cylinder,	0.490	0.588	427.3	0.490	0.537	445.1	0.490	0.480	468.1

47. From the preceding calculations we discover some interesting results.

1st. We observe that, in guns of great resistance there is no advantage, with the forms of grain used, in taking the density of loading notably less than the gravimetric density of the charge. We can reduce the density of loading and retain the same velocity by a correlative diminution of the duration of combustion, but this augments the pressure.

If we regulate the duration of combustion in a manner to retain the pressure we diminish the velocity.

In guns of little strength, there is on the other hand always an advantage in adopting densities of loading less than the gravimetric density of the charge.

2d. In bronze guns, with powder grains of the form of a cube, sphere or parallelopipedon (generally used), the velocity cannot pass beyond 400 to 410 meters with a charge of $\frac{1}{5}$ the weight of the projectile. This limit may, however, be exceeded with the same charge using pierced cylindrical or prismatic grains. The calculation indicates finally that the limit of velocities is from 420 to 430 meters, firing ordinary powder with a charge $\frac{1}{4}$ the weight of the projectile.

These various results may be generalized and extended to different calibres by the application of the principle of similitude.

48. Theory attributes a remarkable superiority, from a ballistic point of view, to pierced cylindrical or prismatic grains.

This theoretical result should, however, be accepted with some reserve. It is exclusively due to the particular law followed in the combustion of a grain, and in practice the law would not hold good in the case of the rupture or disintegration of the grains. Again, the method adopted in the packing of the grains in the cartridges influences their ignition.

For these reasons we shall only consider the figures obtained by prismatic powders as the superior limits of velocities which may be obtained.

PART V.

ADDITIONAL PRACTICAL FORMULÆ.

1. The formulæ which give the velocity and pressure in guns have already been given. To this end, a mixed method has been used; the general form of the equations having been established by theoretical considerations, and the numerical values of certain coefficients determined by experiment.

In particular, to obtain one of the coefficients, it was assumed, conformably to the results of experiments made by the committee at Gavre, that, if all the other elements are constant, the initial velocity is (1) proportional to the $\frac{6}{10}$ power of the weight of the charge, and (2) inversely proportional to the $\frac{1}{4}$ power of the capacity of the powder chamber.

2. Now, it is known that, in certain cases, it is better to take the velocity proportional to the $\frac{5}{8}$ power of the weight of the charge.*

We shall examine, in this note, the modifications which the formulæ will undergo in this hypothesis.

The form of this new discussion differs in one point from that previously adopted. It shows that, in the ordinary conditions of fire, the two empirical laws, according to which the initial velocity depends upon the charge and the volume of the powder chamber, are not distinct.

If one of them is admitted, the other results from it; this reduces the number of data which must be determined by experiment.

3. *Formula for initial velocities.*—Calling

ϖ the weight of the charge of the powder,
p the weight of the projectile,
u the length the shot moves in the gun,
c the calibre or diameter of the bore,
Δ the density of loading,
f the force of the powder,

*Memorial de l'artillerie de la marine, tome I, p. 643; tome II, p. 40; tome V, p. 401.

τ the time of combustion of a grain under atmospheric pressure,
δ the real density of the powder,
a, λ, numerical coefficients depending upon the form of the grain,
A, B, γ coefficients independent of the elements of fire;
the initial velocity may be represented by the formula (see Part IV, (6)),

$$(1) \qquad v = A\left(\frac{fa}{\tau}\right)^{\frac{1}{2}}\left(\frac{\varpi}{p}\right)^{\frac{1}{4}}\left(\frac{\varpi}{c^2}\right)^{\frac{1}{2}-\gamma}\left(\frac{1}{\Delta}-\frac{1}{\delta}\right)^{\frac{1}{4}-\gamma} u^{\gamma}\left[1 - B\frac{\lambda}{\tau}\frac{(pu)^{\frac{1}{2}}}{c}\right].$$

4. *Formula for pressures.*—The maximum mean internal pressure is given by the formula (see Part IV, (17)),

$$(2) \qquad P = K\frac{fa\,(p\varpi)^{\frac{1}{2}}}{\tau c^2}\left(\frac{1}{\Delta}-\frac{1}{\delta}\right)^{-\frac{1}{2}},$$

the coefficient K being, like A and B, independent of the elements of fire.

5. The expressions (1) and (2) may be simply reduced to more convenient forms, as follows: It is known that a function is sensibly constant near a maximum. Now, in the ordinary conditions of practice, the ratio $\frac{\Delta}{\delta}$ differs little from the value $\frac{1}{2}$, which gives to the function $\frac{\Delta}{\delta}\left(1-\frac{\Delta}{\delta}\right)$ its greatest value equal to $\frac{1}{4}$. We have then, nearly,

$$\frac{\Delta}{\delta}\left(1-\frac{\Delta}{\delta}\right) = \frac{1}{4},$$

and, consequently,

$$(3) \qquad \frac{1}{\Delta}-\frac{1}{\delta} = \frac{1}{4}\cdot\frac{\delta}{\Delta^2}.$$

6. *Reduction of the velocity formula.*—Recollecting the approximate relation (3), we may substitute for the factor $\left(\frac{1}{\Delta}-\frac{1}{\delta}\right)^{\frac{1}{4}-\gamma}$ of (1) the product of

$$\frac{\Delta^{2\gamma-\frac{1}{2}}}{\delta^{\gamma-\frac{1}{4}}}$$

by a numerical factor which may be compounded with A.

Also, calling s the capacity of the powder chamber, we have $\Delta = \frac{\varpi}{s}\cdot$ The formula for velocity may therefore be written,

$$(4) \qquad v = A\left(\frac{fa}{\tau}\right)^{\frac{1}{2}} \frac{\varpi^{\frac{1}{4}+\gamma}\, s^{\frac{1}{2}-2\gamma}\, u^{\gamma}}{p^{\frac{1}{4}}\, c^{1-2\gamma}\, \delta^{\gamma-\frac{1}{4}}}\left[1 - B\frac{\lambda}{\tau}\frac{(pu)^{\frac{1}{2}}}{c}\right].$$

7. It is thus apparent that the exponents of the variables ϖ and s are not independent. Putting them equal to q and r, we have

$$2q + r = 1.$$

If we suppose the velocity proportional to the $\frac{5}{8}$ power of the charge, $q = \frac{5}{8}$; and, consequently, $r = -\frac{1}{4}$. Therefore the velocity is inversely proportional to the $\frac{1}{4}$ power of the capacity of the powder chamber.

If the conditions of fire are such that we are led to ascribe to q a less value than $\frac{5}{8}$, the corresponding value of r decreases in absolute value. For example, we have $r = -\frac{1}{5}$, for $q = \frac{6}{10}$. This consequence of calculation agrees with the experimental facts.*

8. We have, $q = \frac{1}{4} + \gamma$. If then we assume $q = \frac{5}{8}$, we have $\gamma = \frac{3}{8}$. In this hypothesis, (4) becomes

$$(5) \qquad v = A\left(\frac{fa}{\tau}\right)^{\frac{1}{2}} \frac{\varpi^{\frac{5}{8}}\, u^{\frac{3}{8}}}{(pcs)^{\frac{1}{4}}\, \delta^{\frac{1}{8}}}\left[1 - B\frac{\lambda}{\tau}\frac{(pu)^{\frac{1}{2}}}{c}\right].$$

The value of the density δ varies within rather narrow limits in practice. We may then, without sensible error, neglect the corresponding variations of $\delta^{\frac{1}{8}}$, and consider this factor, reduced to its mean value, as comprised in the coefficient A.

Restoring then the density of loading, we have for the definitive formula for velocity

$$(6) \qquad v = A\left(\frac{fa}{\tau}\right)^{\frac{1}{2}} (\varpi u)^{\frac{3}{8}} \left(\frac{\Delta}{pc}\right)^{\frac{1}{4}}\left[1 - B\frac{\lambda}{\tau}\frac{(pu)^{\frac{1}{2}}}{c}\right].$$

9. *Reduction of the pressure formula.*—Replacing in (2) the factor $\frac{1}{\Delta} - \frac{1}{\delta}$ by the approximate value (3), neglecting the variations of the square root of δ, and supposing the constant factors comprised in K, we find an expression of the form

$$P = K\frac{fa\Delta\,(p\varpi)^{\frac{1}{2}}}{\tau c^2},$$

similar to formula (18) of the preceding part.

* Memorial; tome V, p. 401.

We deduce from this the two following approximate laws:

All other elements in a gun being constant, the maximum pressure is,

1st. Proportional to the $\frac{3}{2}$ power of the weight of the charge;

2d. Inversely proportional to the capacity of the powder chamber.

As this reduction of the formula for pressures results from the assumption made in No. 5, it is necessary, in order that these two laws shall be exact, that the ratio $\frac{\Delta}{\delta}$ shall not differ much from $\frac{1}{2}$.

We believe, however, that this approximation will suffice, in practical applications, in the determination of a quantity which cannot at present be precisely found.

10. *Determination of the coefficients A and B of the formula for velocity.*—The change in the formula requires that these shall be again determined. This may be done by supposing (see Part IV, Nos. 8 and 9) that the standard powder, defined by the data

$$f = 431000, \quad \tau = 0.730, \quad a = 3, \quad \lambda = 1,$$

will give, in the 24 cent. and 14 cent. guns, velocities of 437.1m. and 438.4m., in the conditions of fire specified in the table of No. 9.

We have thus two equations which give the values,

$$A = 1.691, \quad B = .00831,$$

the units being the kilogram, decimeter, and second.

11. *Formula for velocities.*—Introducing these values in (6), and calling α and β the characteristics (Part IV, No. 7) of the powder, we have

$$(7) \qquad v = 1.691\alpha\,(\varpi u)^{\frac{3}{8}}\left(\frac{\Delta}{pc}\right)^{\frac{1}{4}}\left[1 - .00831\beta\,\frac{(pu)^{\frac{1}{2}}}{c}\right].$$

Such is the new formula we wished to establish.

12. *Experimental determination of the characteristics of a powder.*—It has already been shown (Part IV, No. 17) how this may be done.

With the new formula, the process should be as follows:

Put, for shortness

$$(8) \qquad \begin{cases} 1.691\,(\varpi u)^{\frac{3}{8}}\left(\dfrac{\Delta}{pc}\right)^{\frac{1}{4}} = \dfrac{1}{X}, \\[2ex] .00831\,\dfrac{(pu)^{\frac{1}{2}}}{c} = Y, \end{cases}$$

equation (7) may then be written,

$$Xv = \alpha - \alpha\beta Y.$$

Calling X_1, Y_1; X_2, Y_2, two particular values of X and Y, and v_1 and v_2 the corresponding measured velocities, we have

$$(9) \qquad \begin{cases} X_1 v_1 = \alpha - \alpha\beta Y_1, \\ X_2 v_2 = \alpha - \alpha\beta Y_2; \end{cases}$$

which give α and β.

If we use in the determination the fire of the 24 and 14 cent. guns in the conditions already given (Part IV, No. 9), the numerical values of X and Y are as follows:

$$24 \text{ cent. gun} \begin{cases} X_1 = 0.19825 \\ Y_1 = 0.25465 \end{cases}$$

$$14 \text{ cent. gun} \begin{cases} X_2 = 0.24474 \\ Y_2 = 0.14144 \end{cases}$$

In particular, for the A_3B powder, giving 439.7m. in the 24 cent. and 441.6m. in the 14 cent. piece, we have the values,

$$\alpha = 1342, \quad \beta = 1.376,$$

which are the same as those found with the formula of Part IV (see Part IV, No. 19). Also, these quantities being the basis of the calculation of the characteristics of the ordinary French powders, it is evident the table of No. 22 of Part IV may be used in the practical applications of (7).

13. With regard to the figures of this table, it may be well to note the following relative to the four French powders.

The characteristics were calculated upon the assumption that the grains are parallelopipedons with square bases. We thus suppose a regularity of form which the method of screening does not always secure. In fact, the fabrication determines only one dimension, that of the thickness of the cake, with precision. Perpendicularly to the thickness, the dimensions vary irregularly within certain limits.

It may then be more exact to assume, *as a mean*, that the grain is flattened cylinder, whose radius may easily be deduced from the thickness and density, and the number of grains to the kilogram.

The values of α and β, calculated in this hypothesis, are as follows:

Name of Powder.	Characteristics. α	β
SP_2	1297	1.266
SP_1	1570	1.913
C_1	1746	2.347
C_2	2064	3.355

We shall conclude this note by deducing from (6) some relations which may be of use in practice.

14. *Maximum velocity.*—It has already been remarked (Part IV, No. 28) that, if τ is considered a variable, and all the other quantities are constants, the velocity passes through a maximum. If we call τ_1 the value of τ which corresponds to this maximum, we have (see Part IV, No. 29),

$$\tau_1 = 3B\frac{\lambda(pu)^{\frac{1}{2}}}{c},$$

and the corresponding velocity is of the form,

$$(10) \qquad v_1 = A_1\left(\frac{fa}{\lambda}\right)^{\frac{1}{2}}\frac{\varpi^{\frac{3}{8}}\Delta^{\frac{1}{4}}c^{\frac{1}{4}}u^{\frac{1}{8}}}{p^{\frac{1}{2}}},$$

the value of A_1 being*

$$A_1 = \frac{2}{3}A(3B)^{-\frac{1}{2}}.$$

This new value of v_1 shows that, if the powder used differs little from that which will give the maximum velocity, and if the travel of the shot varies between narrow limits, the *initial velocity is sensibly proportional to the $\frac{1}{8}$ power of that travel.*

15. *On the greatest value of the velocity corresponding to a given value of the maximum pressure.*—The theoretical formula for velocity leads also to the following result (Part IV, No. 42). Among the systems of values of Δ and τ which give the same pressure, there is one for which the velocity will be a maximum.

Let us call τ_0 and Δ_0 the values of τ and Δ which, for a given value of P, give the maximum velocity. We easily find,

$$\tau_0 = .04155\frac{\lambda(pu)^{\frac{1}{2}}}{c},$$

$$\Delta_0 = 2.716\frac{\lambda c u^{\frac{1}{2}}}{fa\varpi^{\frac{1}{2}}}P,$$

$$v_0 = 8.520\left(\frac{fa}{\lambda}\right)^{\frac{1}{4}}\frac{\varpi^{\frac{1}{4}}u^{\frac{1}{4}}c^{\frac{1}{2}}}{p^{\frac{1}{2}}}P^{\frac{1}{4}}.$$

16. The preceding formulæ represent the facts of experiment with an exactness which is sensibly the same as in the use of those which were established in the hypothesis that the initial velocity is proportional to the $\frac{6}{10}$ power of the charge, and inversely proportional to the $\frac{1}{4}$ power of the density of loading. They are perhaps simpler and more convenient for purposes of application.

*Replacing A and B by their values found in No. 10, $A = 1.661$, $B = 0.00831$, we find the numerical value of A_1 to be 7.140.

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METHOD OF TESTING CHRONOMETERS AT THE U. S. NAVAL OBSERVATORY.

By Lieutenant E. K. Moore, U. S. N.

In the appropriation for the fiscal year ending June 30, 1883, provision was made for the construction of a house in which to test chronometers at different temperatures. Under that provision the present temperature room was built.

It is situated on the north side of the Observatory, in an angle of the east wing, directly in front of and connecting with the chronometer room proper. This is a cool and comparatively well-shaded place. The foundation is of brick, and starts from solid earth three feet below the surface, and reaches two feet six inches above it. From just below the surface it is made double, with an air space of the width of one brick between the walls. On top of the foundation, and made tight with cement, is placed a plate of slate; on this plate, and cemented to it, is the sill of the house.

The exterior dimensions are eleven feet eight inches square by ten feet high from the foundation to the eaves, and twelve feet to the ridge. The walls and ceilings are double, made of well-seasoned

lumber, the plank being inch-thick pine, tongued and grooved, placed horizontally, leaving a clear space of eight inches between. This space is filled with dry and well-seasoned sawdust, making the sides and ceiling ten inches thick, of wood.

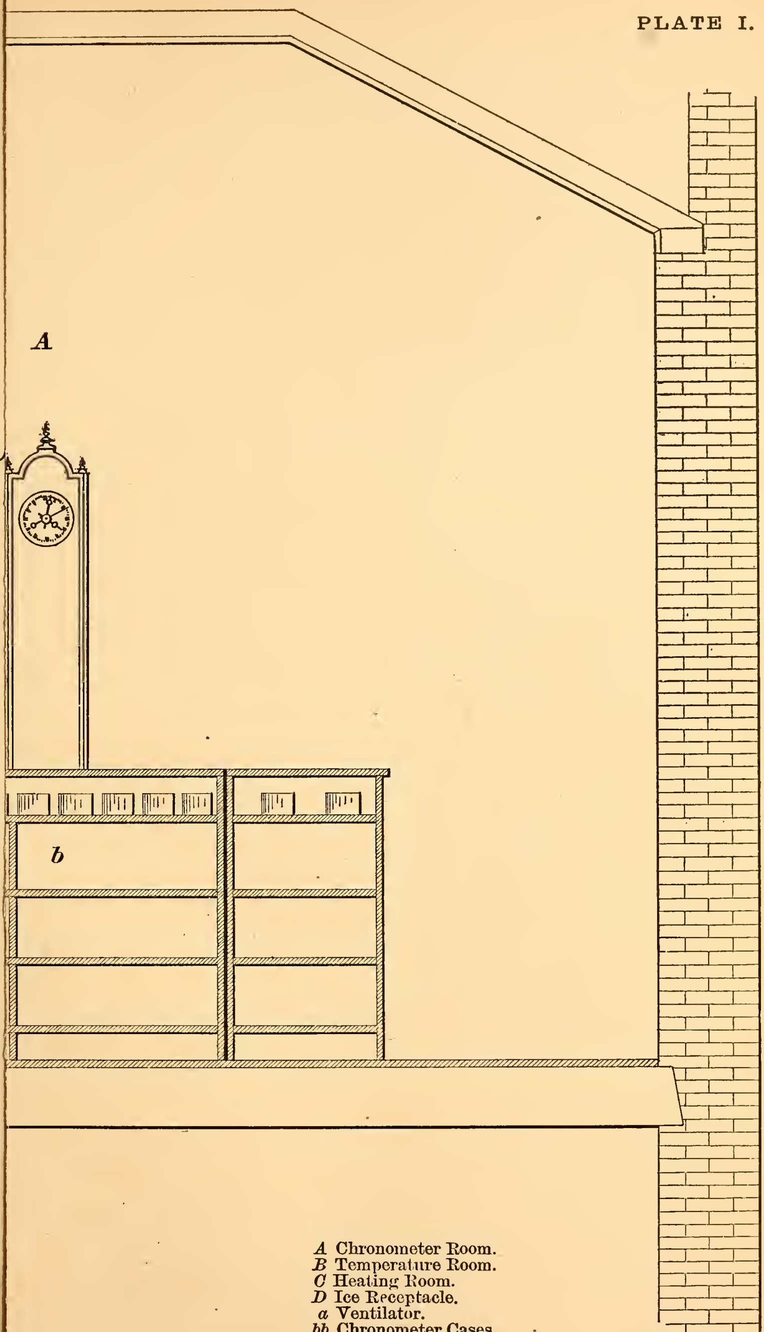
It is covered with a tin roof, leaving an air space of from two to four feet between the upper ceiling and the roof.

There are two floors, the lower of which is on a level with the surface of the earth, and is made of ordinary pine flooring, built in, and made tight with the foundation. The upper one is at the top of the foundation, and is made of strips two inches wide by one inch thick, laid so as to leave an inch space between them, the whole covered with sheet zinc, turned up two inches at the sides, and tacked to the inner wall with thick felt between the zinc and the wall. This makes the room tight from the space between the floors, which is the ice receptacle or refrigerator, in which the air is at or near saturation when ice is used. The refrigerator is eight feet square by two feet six inches high, and is capable of holding two thousand pounds of ice. A few hundred, however, is all that will be usually required, and for this there are two troughs, one on either side of the centre, six feet long by two feet wide, and eight inches deep, lined with zinc, and fitted with drain pipes leading to the outside of the building. These troughs will hold three or four hundred pounds each. To get into the refrigerator, there are double doors through the foundation, one at the outer, and the other at the inner surface of the wall, each fitted tight with a lining of felt, leaving a space between the doors of the thickness of the foundation.

The temperature room is ten feet square by seven feet high, and is also fitted with double doors, the outer one of which connects directly with the main clock and chronometer room. Both doors are made tight with linings of felt, and the inner one has a large plate of French glass in its upper half, through which the face of the mean time standard clock can be plainly seen when the outer door is open. With this clock all chronometers are compared daily.

Between the doors, and made tight with them, is a passage-way, four feet long, four feet wide and seven feet high, made in the same manner as the house, with double walls and ceiling. It is large enough for two persons to stand between the doors and close one before opening the other, thus excluding a rush of outside air of a different temperature.

For lighting the room there is one window on the north side,



A Chronometer Room.
B Temperature Room.
C Heating Room.
D Ice Receptacle.
a Ventilator.
bb Chronometer Cases.

lumber, the plank being inch-thick pine, tongued and grooved, placed horizontally, leaving a clear space of eight inches between. This space is filled with dry and well-seasoned sawdust, making the sides and ceiling ten inches thick, of wood.

It is covered with a tin roof, leaving an air space of from two to four feet between the upper ceiling and the roof.

There are two floors, the lower of which is on a level with the surface of the earth, and is made of ordinary pine flooring, built in, and made tight with the foundation. The upper one is at the top of the foundation, and is made of strips two inches wide by one inch thick, laid so as to leave an inch space between them, the whole covered with sheet zinc, turned up two inches at the sides, and tacked to the inner wall with thick felt between the zinc and the wall. This makes the room tight from the space between the floors, which is the ice receptacle or refrigerator, in which the air is at or near saturation when ice is used. The refrigerator is eight feet square by two feet six inches high, and is capable of holding two thousand pounds of ice. A few hundred, however, is all that will be usually required, and for this there are two troughs, one on either side of the centre, six feet long by two feet wide, and eight inches deep, lined with zinc, and fitted with drain pipes leading to the outside of the building. These troughs will hold three or four hundred pounds each. To get into the refrigerator, there are double doors through the foundation, one at the outer, and the other at the inner surface of the wall, each fitted tight with a lining of felt, leaving a space between the doors of the thickness of the foundation.

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For lighting the room there is one window on the north side,

PLATE I.

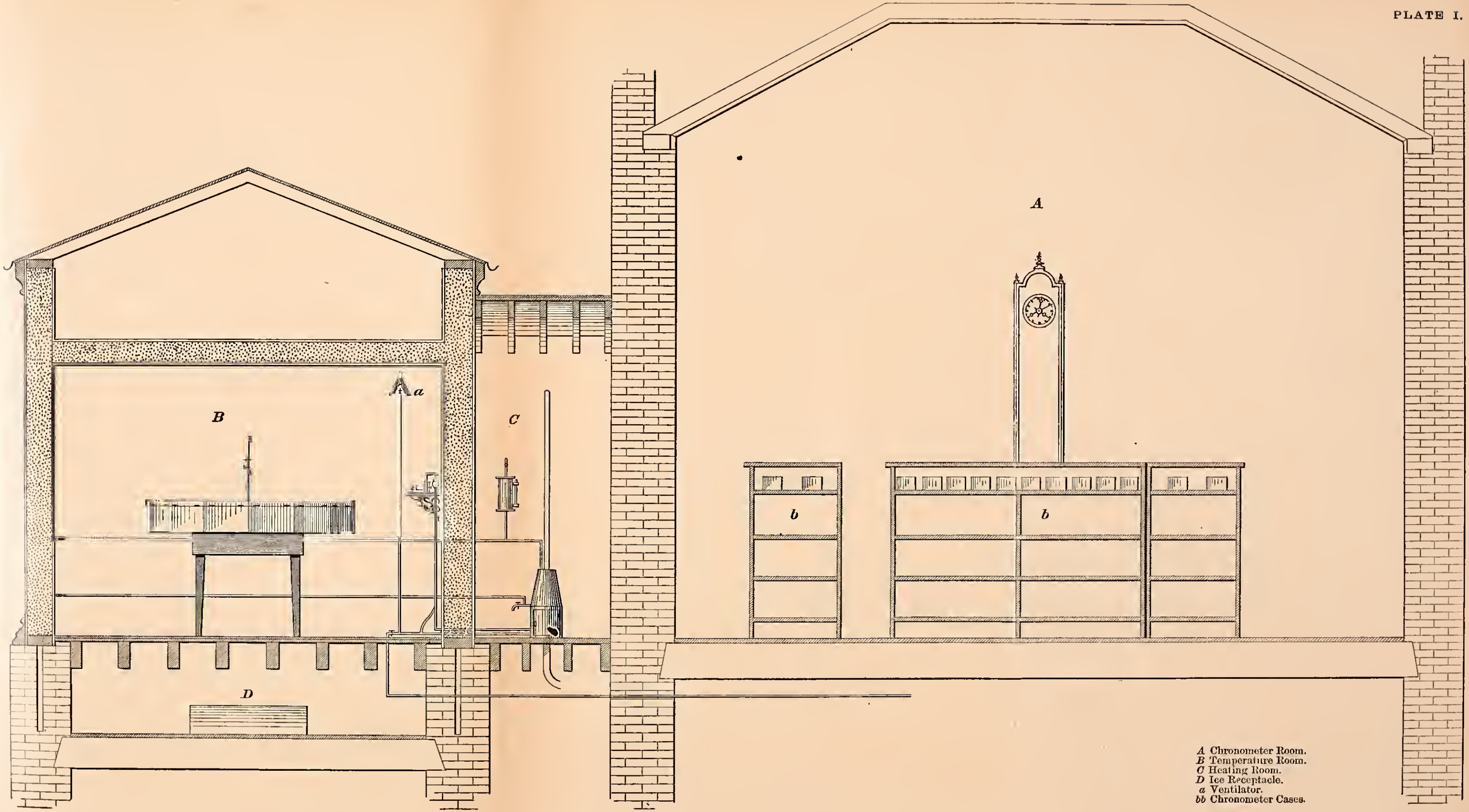
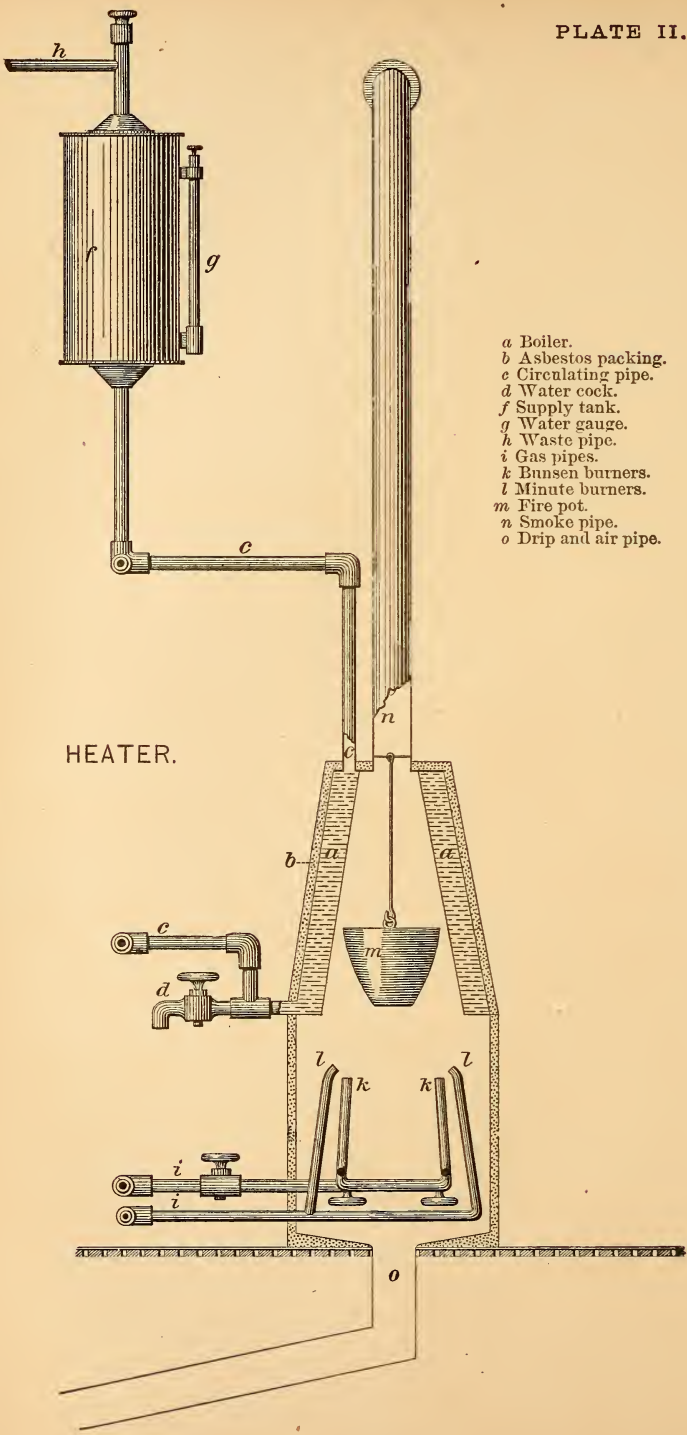

A
B
a
C
b
b
D
A Chronometer Room.
B Temperature Room.
C Heating Room.
D Ice Receptacle.
a Ventilator.
bb Chronometer Cases.

PLATE II.



a Boiler.
b Asbestos packing.
c Circulating pipe.
d Water cock.
f Supply tank.
g Water gauge.
h Waste pipe.
i Gas pipes.
k Bunsen burners.
l Minute burners.
m Fire pot.
n Smoke pipe.
o Drip and air pipe.

HEATER.

opposite the door, having a double sash. The outer one is three feet high by two feet wide, and the inner one three feet high by two and a half wide; the casing is beveled so as to admit light to all parts of the room. Both sashes are screwed in with felt between the casing and the sashes, leaving an air space of six inches between the glasses.

The room is heated by circulation of hot water (the fuel being gas controlled by electricity), and is cooled by ice in the refrigerator when a temperature is required below that of the outside atmosphere.

In a small room, two and a half feet by three and a half, and six feet high, built between the temperature and main chronometer rooms, and connecting by door with the small passage-way, is a small copper boiler, made in the shape of the frustum of a cone. The boiler and heating space underneath are covered with a casing of copper, leaving a space of half an inch between the boiler and casing, which is filled with asbestos packing.

From the top of the boiler leads the circulating pipe (of iron and an inch in diameter), which goes through the wall, where it is surrounded by asbestos packing, into the temperature room, thence twice around the room, back through the wall and into the boiler at its lowest point, making a fall of eighteen inches in circulating. A water-cock is placed on the return pipe near the boiler for drawing off the water when not in use.

Above the boiler and connecting with the circulating pipe is a supply tank of galvanized iron, holding about one gallon of water. This is fitted with an opening at the top for filling, a glass water-gauge at the side, and a waste-pipe leading from the top out through the side of the building. This latter is a safety as well as an overflow pipe, for should the control cease to act and too much heat be generated, the steam would escape through this pipe and relieve the pressure in the circulating coil.

A gas pipe leads from the main pipe of the Observatory through the foundation up into the temperature room, with its main cock just above the floor. Thence the pipe is led up the wall about four feet, over a little shelf; thence down to the floor, through the wall into the heating room, and under the boiler where the two Bunsen burners are attached. In the horizontal part of this pipe, over the small shelf, is a spring valve acting perpendicularly, the spring keeping the valve open. The stem of the valve projects above the box, and is worked automatically by a lever attached to the armature of an electro-magnet.

A small gas pipe leads from the main pipe, before it reaches the automatic valve, to the top of the room, with its burner under a funnel-shaped ventilator, for increasing the draught and regulating the hygrometric state of the room.

Another small gas pipe leads from the same point through the wall into the heating room and under the boiler, where two minute burners are attached, the flames from which are directed, one over each Bunsen burner. These are always kept burning when the room is in use.

A two-inch pipe leads through the floor and foundation to the outside for supplying cold air as required. This, with the ventilator, is regulated by hand.

Suspended over the Bunsen burners in the hollow space of the boiler is a fire-pot to deflect the flames against the sides, and from the top of this space a small copper pipe leads up to the ceiling and out through the wall, for the escape of the products of combustion. Directly under the burners, leading through the floor and out through the foundation, is a two-inch lead pipe to carry off condensed vapor and to supply oxygen to the burners. A small, tight-fitting door opens into the combustion chamber.

The supply of gas is controlled by electricity through a mercurial thermostat, the stem of which is made and graduated like an ordinary thermometer, but which is open at the top.

The bulb is made of a thin glass tube coiled into a flat spiral. A fine platinum wire is fused into the end and connects with the mercury, its other end being secured to a binding-post. The thermostat is secured in a vertical position to a stand which is placed on the centre of the table upon which the chronometers to be tested are placed. A small platinum wire passes down into the upper end of the thermostat, and is secured at its upper end to a binding-post on the top of the stand.

A delicate and plainly graduated maximum and minimum thermometer is also attached to the stand, and, with the bulb of the thermostat, is placed on a level with the chronometers.

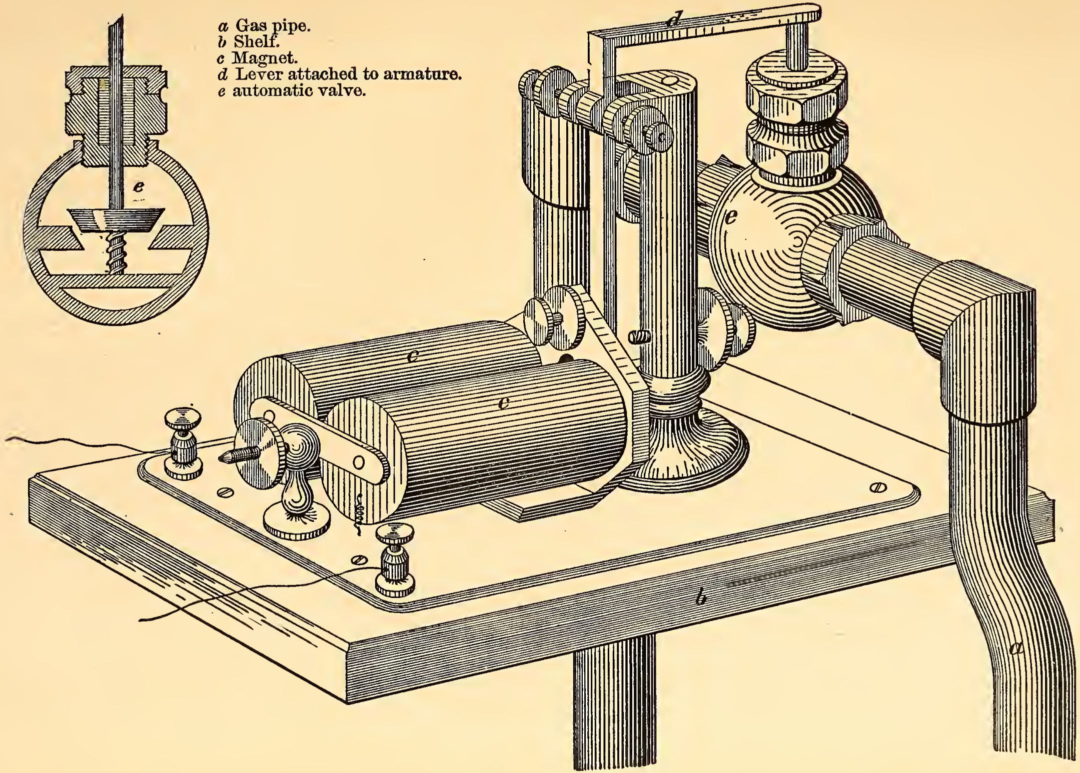
The controlling circuit leads from one pole of the battery to the binding-screw at the top of the stand, from there through the platinum wire, mercury column, and platinum wire to the other binding-screw; thence to the spools of an electro-magnet placed on the small shelf by the automatic valve, and thence back to the battery.

A condenser, or spark-arrester, is placed in the circuit between the binding-posts of the thermostat.

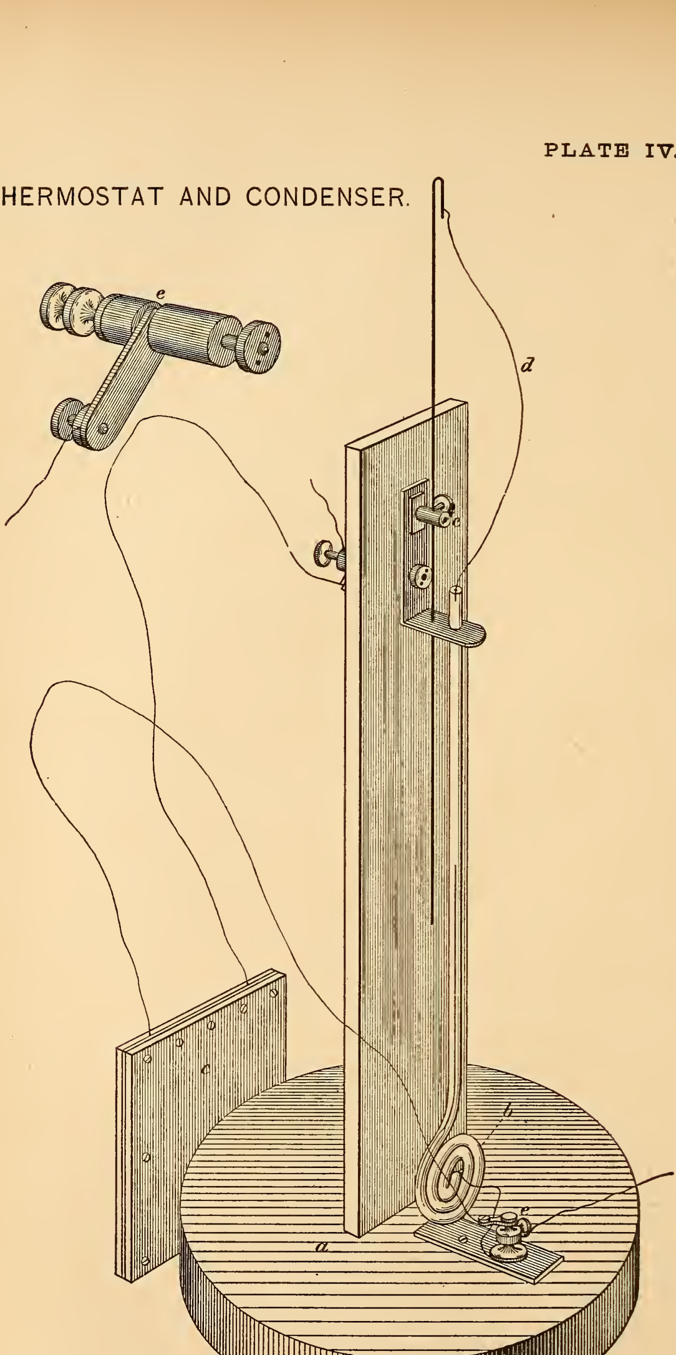
PLATE III.

AUTOMATIC VALVE AND CONTROLLING MAGNET.

a Gas pipe.
b Shelf.
c Magnet.
d Lever attached to armature.
e automatic valve.



THERMOSTAT AND CONDENSER.



When in use the platinum wire is adjusted so that the end in the tube indicates the temperature at which the room is to be kept, and the small gas jets are lighted. Suppose the temperature of the room to be below that required, the mercury column will not be in contact with the platinum wire, and the circuit will be open. In this condition the valve will be open, gas flowing and burners burning, which will continue until the temperature rises and closes the circuit by contact between the mercury and platinum; this attracts the armature and closes the valve. This continues until the temperature falls enough to break the circuit, when the same action is repeated.

This is found to work in a very satisfactory manner during the six colder months of the year; the temperature of the room is kept within a range of two degrees, and not unfrequently for forty-eight hours within one degree. By covering the circulating coils with large sheets of close wrapping paper, folded in the middle and dropped over the pipes, leaving the bottom open, the range of temperature is decreased about one-half.

The table on which the chronometers are placed is circular, and stands in the middle of the room, with the control and automatic thermometers in its centre. Each chronometer has a separate compartment, large enough to receive the chronometer and leave a space of an inch or more between its case and the walls of the compartment, each compartment being fitted with a separate lid. Holes are bored in the bottoms of the compartments to allow a free circulation of air, and the lids are left open except at the time of comparing, when they are all closed except that of the chronometer under comparison. The object of this is to permit the comparisons by ear to be made more easily.

A hygrometer is used for testing the moisture in the air, and is left in the room only long enough to determine the daily percentage.

All of the chronometers are compared daily between 11 and 11.40 A. M. with the mean time standard clock, and the errors and rates are worked up every seventh day, called term day; from these mean rates all calculations are made. Comparisons are made to the nearest quarter of a second. The temperature is closely observed each day at comparison and recorded for the previous twenty-four hours, by a chronometric thermometer (a chronometer not compensated for temperature), and by self-registering maximum and minimum thermometers.

All chronometers received, either new, or after having been cleaned

and repaired, are placed on trial for six months before their purchase, if new, or before their issue, if old ones. The trials should commence near the middle of summer or the middle of winter in each year, so that the natural temperatures of both the extremes can be used as well as artificial ones.

All chronometers on being placed on trial have the tops of their boxes removed for convenience in comparing, and in order to make them more sensitive to the surrounding temperature. They are examined to see that they fit properly in their gimbals, work perfectly free and without jar, and hang with their faces horizontal.

Some time during the cooler months of their trial they are placed in the temperature room for about fifty days, during which time they are given two tests at three different temperatures, one set going from a lower to a higher, and the other from a higher to a lower temperature, always beginning with one extreme and ending with the same. By this means the effect of time on the rate is eliminated.

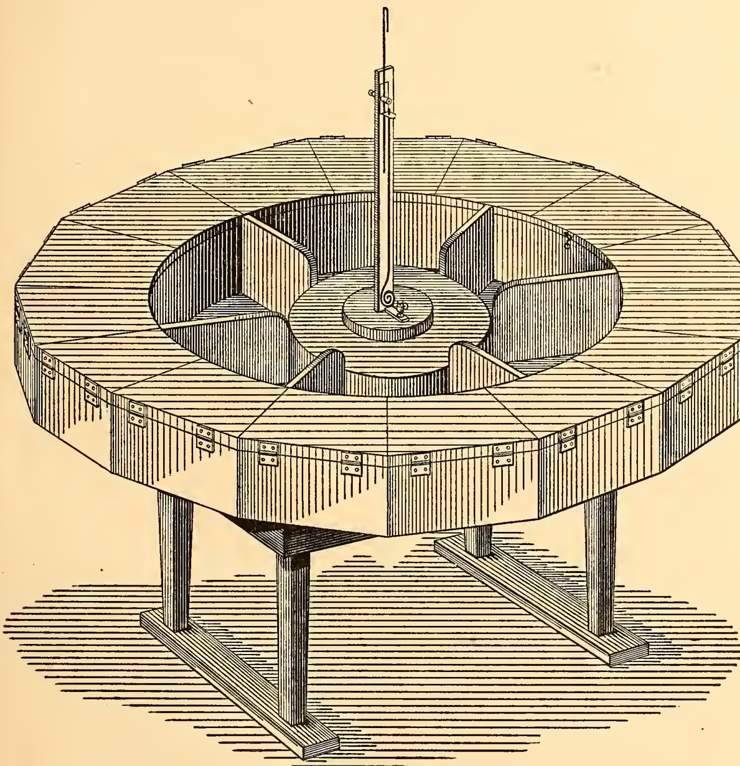
Any three temperatures between 45° and 90° Fahr. may be used, as between these points with the ordinary chronometer the changes of rate, owing to temperature alone, are proportional to the squares of the differences of temperature from the temperature of compensation, or fastest running. Fifty-five, seventy, and eighty-five degrees are good temperatures to use, as between these extremes are included all the temperatures through which chronometers will pass in ordinary navigation. These temperatures need not be equidistant, as is the case in Hartnup's method, but may be taken as most convenient.

Suppose we begin this test with 55° as the lowest temperature. The chronometers are placed in the room with the temperature at 52° or 53° for a day or two, when it is raised to 55°, and kept so for a term of seven days; it is then raised slowly to 70° and allowed to remain a day or two at that point before beginning the term at that temperature. After seven comparing days at 70°, the temperature is raised slowly to 85°, and allowed to stand a day or two, and then a seven day term is noted as before. The temperature is then raised to about 90°, allowed to stand a day or two, then lowered to 85°, and the same tests made again, only in reverse order.

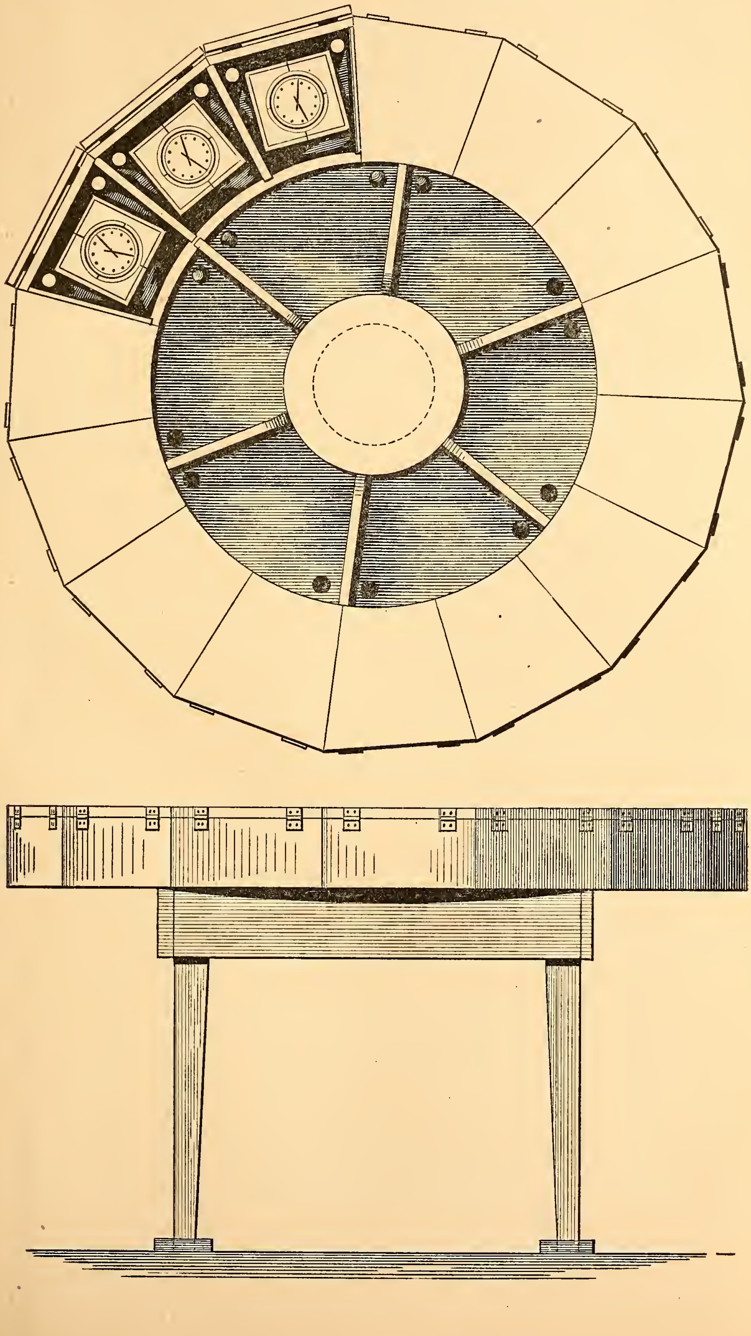
Great care must be exercised, especially in lowering the temperature, to keep the hygrometric state of the air in the room about the same, and in no case to allow it to approach saturation. At each change of temperature a day or two is allowed the chronometers in

PLATE V.

CHRONOMETER TABLE AND THERMOSTAT.



CHRONOMETER TABLE.



which to settle to their new rates before beginning the term. Some appear too sensitive and overreach themselves, as it were, gradually falling back; others appear too sluggish, reaching their new rates only after standing a time, while others note the change at once.

In making the second test, the exact temperature used in the first may not be obtained, in which case use the mean of the two temperatures as well as the mean of the two rates for calculations.

All chronometers without auxiliary compensation run fastest at some one temperature, which we shall call the temperature of compensation; this should be the mean temperature to which they will be subjected in actual use, and for navy chronometers it is about 69° Fahr.

The change of rate owing to temperature is least near this point, and increases, the chronometer running slower as the temperature recedes from it. The rate is the same for an equal number of degrees above or below the temperature of compensation. This change of rate is proportional to the square of the number of degrees from the point of compensation, differing for different chronometers. Beyond the limits of about 45° to 90° the change in rate is greater, and proportional to a higher power than the square.

Let $\theta°$ be the temperature of compensation; r the rate at $\theta°$; z the temperature constant, or change of rate owing to temperature at one degree from θ; θ' any other temperature, and r' the rate at $\theta'°$.

Then $$r' = r + z(\theta - \theta')^2 \qquad (1)$$
which is the general equation for the effect of temperature alone.

Let d, e, and f be the mean temperatures obtained in the temperature room, and a, b, and c the mean rates at these temperatures respectively. Then,

$$a = r + z(\theta - d)^2$$
$$b = r + z(\theta - e)^2$$
$$c = r + z(\theta - f)^2.$$

Whence, $$\theta = \frac{(b-c)(d^2-e^2)-(a-b)(e^2-f^2)}{2[(a-b)(f-e)-(b-c)(e-d)]} \qquad (2)$$

$$z = \frac{(a-b)}{(\theta-d)^2-(\theta-e)^2} = \frac{(b-c)}{(\theta-e)^2-(\theta-f)^2} \qquad (3)$$

$$r = a - z(\theta-d)^2 = b - z(\theta-e)^2 \qquad (4)$$

$$rn = r + z(\theta - \theta n)^2 \qquad (5)$$

These quantities differ for every chronometer, but θ and z remain practically constant for the same chronometer as long as its compen-

sation remains unchanged; and the chronometer may go through the hands of its maker, be cleaned, oiled and have minor repairs, and yet these constants remain the same. As a fact, in cleaning and repairing chronometers the makers seldom change the temperature compensation unless it is known to be excessive; r is variable and changes with time and conditions which will be treated of hereafter.

The first chronometers were placed in the temperature room about February 1, 1883, and the results of some of the best were as follows:

MEAN DATE, *Feb.* 26, 1883.

No. 729 *Negus.*

Mean temperatures and rates going from a low to a higher temperature:

At 56.1°, rate+0.570s. At 68.0°, rate+0.976s. At 83.1°, rate+0.396s.

Mean temperatures and rates going from a high to a lower temperature:

At 56.5°, rate+0.908s. At 68.6°, rate+1.264s. At 83.5°, rate+0.352s.

Means of the above temperatures and rates:

At 56.3°, rate+0.739s. At 68.3°, rate+1.120s. At 83.3, rate+0.374s.

Substituting the means in formulæ (2), (3), and (4), and solving:

$a = +0.739s.$ $\quad (b-c) = +0.746s.$ $\quad d = 56.3°$ $\quad (f-e) = 15°$

$b = +1.120$ $\quad (a-b) = -0.381$ $\quad e = 68.3$ $\quad (e-d) = 12$

$c = +0.374$ $\quad f = 83.3$

$$d^2 = 3169.69 \qquad e^2 = 4664.89$$
$$e^2 = 4664.89 \qquad f^2 = 6938.89$$
$$(d^2 - e^2) = -1495.20 \qquad (e^2 - f^2) = -2274.00$$
$$(b-c) = +0.746 \qquad (a-b) = -0.381$$
$$(b-c)(d^2 - e^2) = -1115.4192 \qquad (a-b)(e^2 - f^2) = +866.394$$
$$(a-b)(e^2 - f^2) = +866.3940$$
$$\text{diff.} = -1981.8132$$

$$(a-b) = -0.381 \qquad (b-c) = +0.746$$
$$(f-e) = +15. \qquad (e-d) = +12.$$
$$(a-b)(f-e) = -5.715 \qquad (b-c)(e-d) = +8.952$$
$$(b-c)(e-d) = +8.952$$
$$\text{diff.} = -14.667$$
$$2.$$

$$-1981.8132 \div -29.334 = 67.56° = \theta.$$

$(\theta - d) = + 11.26 \quad (\theta - d)^2 = 126.7876$
$(\theta - e) = - 0.74 \quad (\theta - e)^2 = \underline{0.5476}$
$(a - b) = - 0.381 \quad \div \text{diff.} = + 126.24 = - 0.00302s = z$

$$(\theta - d)^2 = 126.7876$$
$$z = \underline{- 0.00302}$$
$$a = + 0.739s - \text{prod.} = - 0.38289s = + 1.122s = r$$

$(\theta - e) = - 0.74 \quad (\theta - e)^2 = 0.5476$
$(\theta - f) = - 15.74 \quad (\theta - f)^2 = 247.7476$
$(b - c) = + 0.746 \quad \div \text{diff.} = - 247.2 = - 0.00302s = z$

$$(\theta - e)^2 = + 0.5476$$
$$z = - 0.00302$$
$$b = + 1.120s - \text{prod.} = - 0.00165s = + 1.122s = r.$$

Substituting the obtained values of θ, z, and r, in formula (5), and solving for every 5°, we have :—

Temp.	Rate.	Temp.	Rate.	Temp.	Rate.
45°	— 0.414s.	60°	+ 0.950s.	75°	+ 0.944s.
50	+ 0.192	65	+ 1.102	80	+ 0.653
55	+ 0.646	70	+ 1.103	85	+ 0.202
				90	— 0.400

No. 1220 *Negus.*

Mean temperatures and rates from temperature room :
At 56.3°, rate + 0.175s. At 68.7°, rate + 0.464s. At 83.3°, rate — 0.201s.

$\theta = 67.07°$. $\quad z = - 0.00255s. \quad r = + 0.471s.$

Temp.	Rate.	Temp.	Rate.	Temp.	Rate.
45°	— 0.771s.	65°	+ 0.460s.	85°	— 0.349s.
50	— 0.270	70	+ 0.449	90	— 0.870
55	+ 0.100	75	+ 0.311		
60	+ 0.334	80	+ 0.045		

MEAN DATE, *May* 1, 1883.

No. 1059 *Negus.*

Mean temperature and rates from temperature room :
At 61.5°, rate — 0.658s. At 73.0°, rate — 0.642s. At 85.1°, rate — 1.175s.

$\theta = 67.62°$. $\quad z = - 0.00188s. \quad r = - 0.588s.$

Temp.	Rate.	Temp.	Rate.	Temp.	Rate.
45°	— 1.550s.	65°	— 0.601s.	85°	— 1.156s.
50	— 1.172	70	— 0.599	90	— 1.530s.
55	— 0.887	75	— 0.690		
60	— 0.697	80	— 0.876		

No. 221 *Bond.*

Mean temperatures and rates from temperature room:

At 61.5°, rate—2.096s. At 73.0°, rate—1.820s. At 85.1°, rate—1.765s.

$\theta = 81.81°$. $z = -0.00083$s. $r = -1.755$s.

Temp.	Rate.	Temp.	Rate.	Temp.	Rate.
45°	— 2.880s.	65°	— 1.989s.	85°	— 1.766s.
50	— 2.595	70	— 1.871	90	— 1.810
55	— 2.351	75	— 1.793		
60	— 2.150	80	— 1.758		

No. 505 *Bond.*

Mean temperatures and rates from temperature room :

At 61.5°, rate+0.626s. At 73°, rate+0.983s. At 85.1°, rate+0.378s.

$\theta = 71.77°$. $z = -0.00343$s. $r = +0.988$s.

Temp.	Rate.	Temp.	Rate.	Temp.	Rate.
45°	— 1.470s.	65°	+ 0.831s.	85°	+ 0.388s.
50	— 0.637	70	+ 0.977	90	— 0.152
55	+ 0.023	75	+ 0.952		
60	+ 0.513	80	+ 0.756		

These rates may be tabulated for every 5° as above; or if the value of z, on which the change depends, is large, for every degree. It is, however, more convenient to have them in the form of a curve, from which the rate at any temperature can be taken at a glance.

Take a sheet of profile or other paper, evenly ruled both ways, plate VII. Let the horizontal lines represent degrees, numbered at the left hand, and the vertical lines tenths of seconds, numbered at the top. Draw a distinctive vertical line, say in red, to represent the zero rate, and let all rates to the right be *plus* or gaining, and all to the left be *minus* or losing. Plot the rate for every 5° as calculated, by making a dot on the temperature line directly under the rate as shown at the top of the card. Draw a free curve passing through each of these points, or, what is better, bend a spline until it is tangent to each of these dots, and rule the curve.

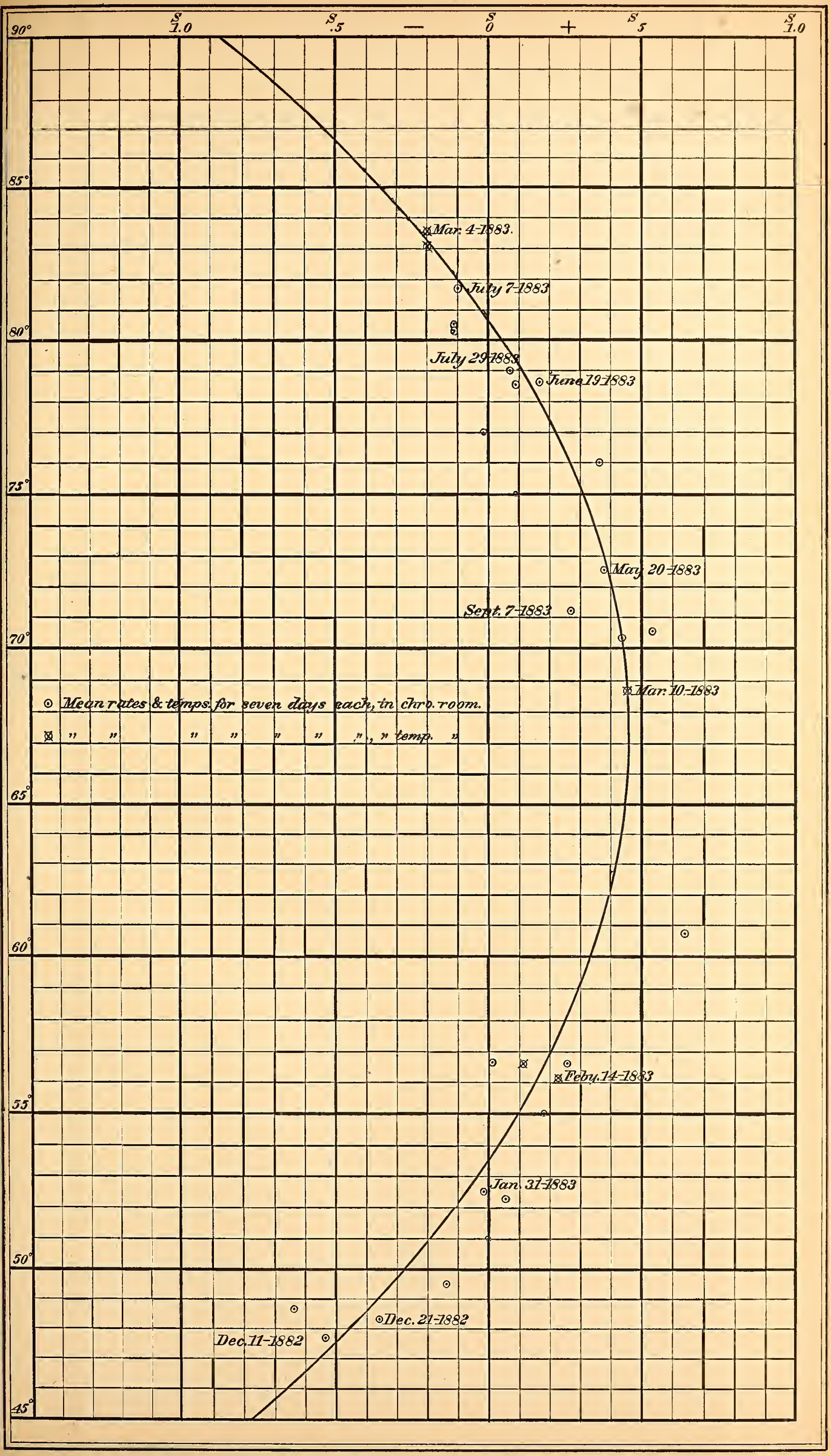
The intersection of this curve with any temperature will be the mean rate for that temperature and is read from the top of the card directly over the intersection.

The position of the zero line will vary with the chronometer, depending on the size and sign of its rate.

Each chronometer running at the Observatory has a card with its curve constructed and rates plotted up to date, so that in the selec-

PLATE VII.

Chro. No. 1220 Negus. Curve and Rates, Nov. 25, 1882, to Sept. 17, 1883.



tion of a chronometer for any purpose, its record since it was last cleaned can be seen at a glance, and the one selected whose compensation is most suited to the temperature in which it is to be used. When the chronometer is issued, a copy of the card goes with it, showing the curve and last rates at different temperatures.

The rates are to be kept plotted during the cruise and the cards returned to the Observatory with the chronometers.

This curve being a parabola, the general equation $y^2 = 4ax$ satisfies all its conditions.

Substitute for y, $(y - b)$ and for x, $(x - c)$;

Whence $$y^2 - 2by - 4ax = -b^2 - 4ac = c' \qquad (6)$$

$$\frac{1}{4a} = \frac{x}{y^2} \qquad (7)$$

$$xn = \frac{1}{4a} v^2 n \qquad (8)$$

From the record of No. 729 Negus, substitute the several values of x and y in (6), letting 68.3° be the axis of x, and 0 seconds the axis of y, and solve for the coordinates of the vertex.

$$x = +1.122\text{s} = r, \text{ and } y = -0.74^\circ \quad \therefore \theta = 67.56^\circ.$$

With coordinates passing through the vertex, from (7),

$$\frac{1}{4a} = -0.00302 = z.$$

Substituting these values in (8) we have,

Temp.	Rate.	Temp.	Rate.	Temp.	Rate.	Temp.	Rate.	Temp.	Rate.
45°	−0.414s.	50°	+0.192s.	55°	+0.646s.	60°	+0.950s.	65°	+1.102s.
70°	+1.103s.	75°	+0.944s.	80°	+0.653s.	85°	+0.202s	90°	−0.400s.

The same are obtained by (2), (3), (4), and (5).

The more accurate the observations for rate and temperature, the more accurate and satisfactory, of course, will be the result; but with the present accurate methods in general use for determining longitude, and the additional facilities for rating by telegraphic signals, time balls, &c., (2), (3), (4), and (5) can be used with close approximation on board cruising vessels where no temperature-rate has been furnished, or for testing that already given.

For this purpose rates should be obtained as frequently as possible, the observer noting carefully the temperature of the chronometers between the observations; for this purpose no chronometer box should be without a good maximum and minimum thermometer. Having obtained a sufficient number of rates at different temperatures, say eight or more, divide them into three sets, putting in each

set, two or more taken at nearly the same temperature. Reject those that differ too greatly from the average temperature of their set, remembering that the change of rate is as the square, and not directly as the difference of the temperature. Reject also any rate that is phenomenal, for the best chronometers will sometimes run wildly for a term or two without apparent cause and then come back again to their usual rates.

Take the mean rate and mean temperature of each set and substitute them in (2), (3), and (4). A convenient way to form the sets is to plot the rates on the card as before described, then to combine in groups those of nearest temperatures and rates.

Chronometer No. 1262 Negus, Plate VIII, was worked up and plotted in this way. It was running at the Observatory from January 6, 1880, to August 18, 1881, when it was issued. It was again returned to the Observatory, March 1, 1883, having been in service afloat. Its record is as follows:

Mean date, April 11, 1880.

	Temp.	Rate.		Temp.	Rate.		Temp.	Rate.
Jan. 16,	59.0°	—1.448s.	Mar. 6,	66.7°	—0.936s.	July 4,	82.5°	—2.180s.
Feb. 15,	56.0	—1.670	Apl. 5,	63.7	—1.145			
Feb. 25,	59.5	—1.394	Apl. 15,	64.5	—0.979	July 14,	84.3	—2.341
Mean,	58.2°	—1.504s.		65.0°	—1.020s.		83.4°	—2.260s.

$\theta = 68.07°$. $z = -0.00550$. $r = -0.968s$.

Mean date, April 29, 1881.

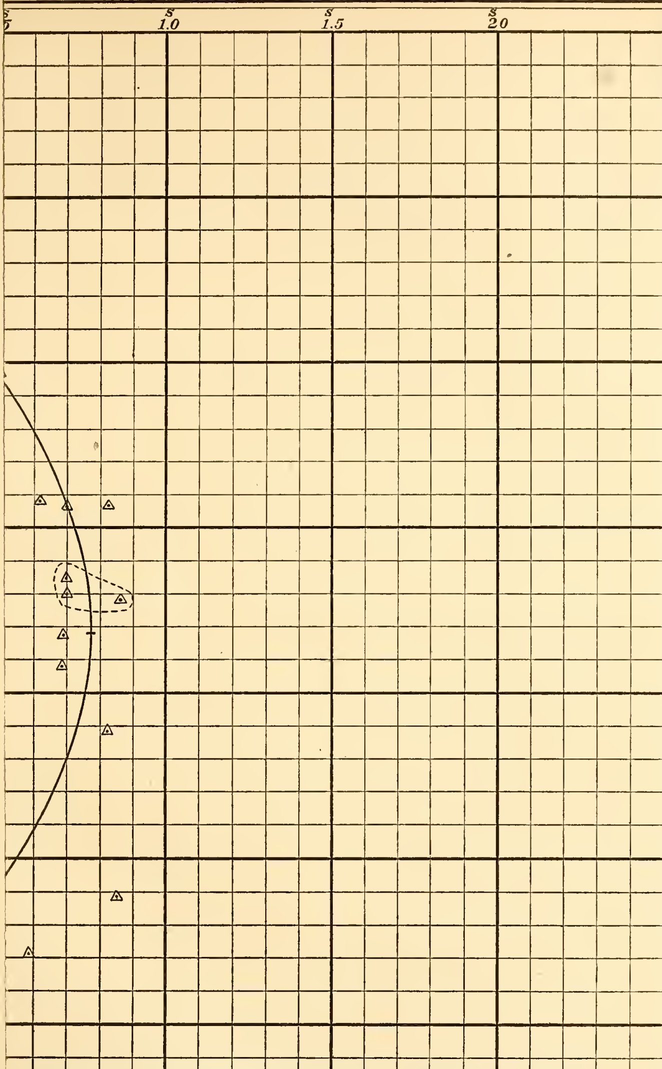
	Temp.	Rate.		Temp.	Rate.		Temp.	Rate.
Jan. 20,	56.5°	—1.694s.	Apr. 10,	71.3°	—0.762s.	July 19,	83.2°	—1.910s.
Jan. 30,	56.6	—1.733				Aug. 8,	82.2	—1.936
Apr. 10,	56.0	—1.297	May 10,	68.9	—0.709	Aug. 18,	81.1	—1.802
Mean,	56.4°	—1.537s.		70.1°	—0.735s.		82.2°	—1.883s.

$\theta = 68.31°$. $z = -0.00604$. $r = -0.716s$.

Mean date, April 17, 1883.

	Temp.	Rate.		Temp.	Rate.		Temp.	Rate.
Mar. 11,	53.8°	—0.768s.	Apr. 21,	73.0°	+0.707s.	Apr. 29,	85.2°	+0.011s.
Mar. 31,	55.0	—0.562	May 19,	72.9	+0.866			
Apr. 6,	55.0	—0.550	June 5,	73.6	+0.696	May 8,	85.0	—0.149
Mean,	54.6°	—0.627s.		73.2°	+0.756s.		85.1°	—0.069s.

$\theta = 71.79°$. $z = -0.00471$. $r = +0.765s$.



d curve, determined by observations from Jan. 6 to July 14, 1880.

Temperature of compensation,		68°.07.
Rate at 68°.07.	—	$0^{s}.968$.
Temperature constant, ...	—	$0^{s}.0055$.

curve, determined by observations from Jan. 1 to July 19, 1881.

Temperature of compensation,		68.°31.
Rate at 68°.31, ...	—	$0^{s}.716$.
Temperature constant, ...	—	$0^{s}.00604$.
Coefficient of time, ...	+	$0^{s}.00067$.

d curve, determined by observations from March 1 to Oct. 23, 1883.

Temperature of compensation,		71°.79.
Rate at 71°.79, ...	+	$0^{s}.765$.
Temperature constant, ...	—	$0^{s}.00471$.
Coefficient of time, ...	+	0.00204,

⊙ × △ Means of rates and temperatures for 7 or 10 days.

set, two or more taken at nearly the same temperature. Reject those that differ too greatly from the average temperature of their set, remembering that the change of rate is as the square, and not directly as the difference of the temperature. Reject also any rate that is phenomenal, for the best chronometers will sometimes run wildly for a term or two without apparent cause and then come back again to their usual rates.

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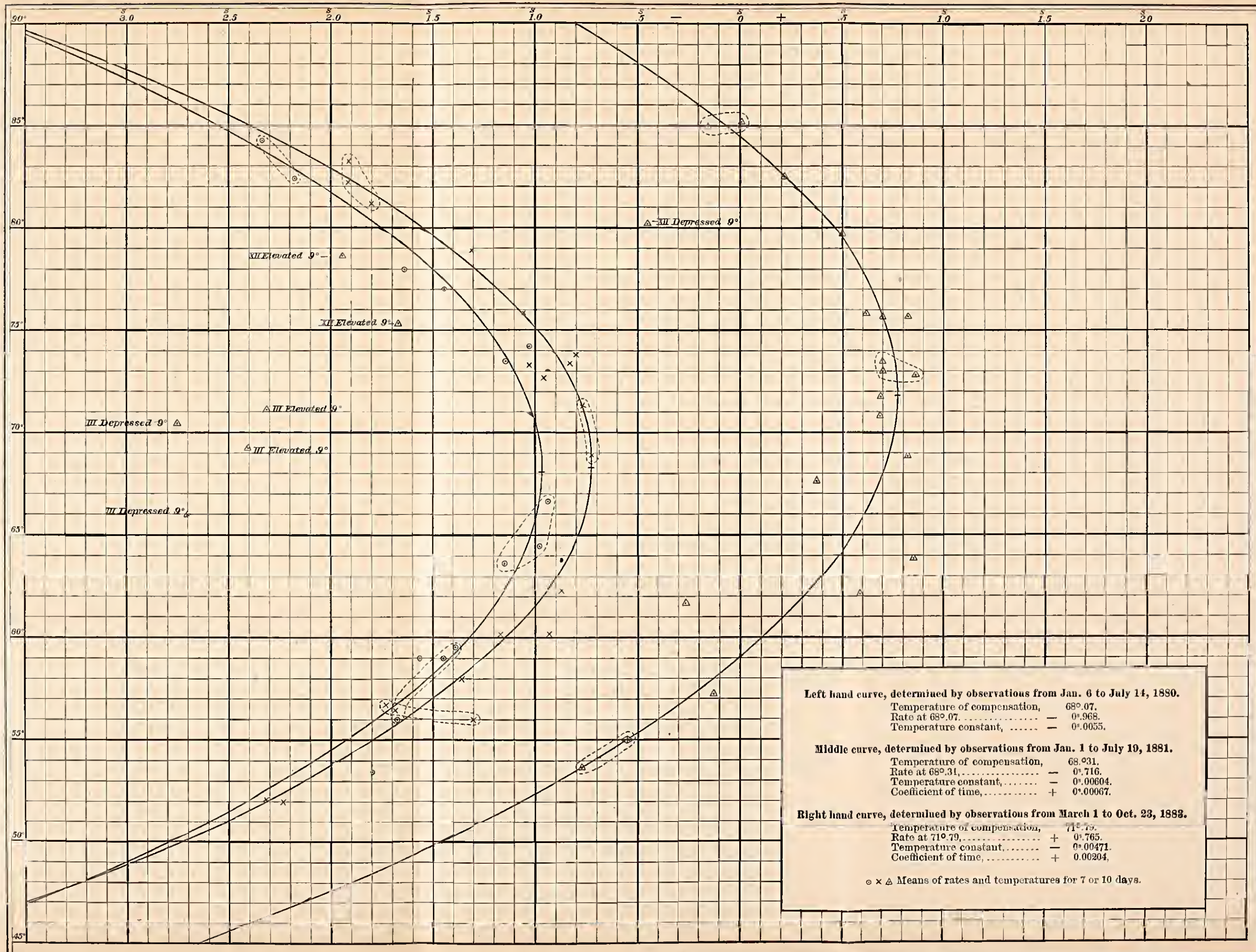
Chro. No. 1262 Negus. Temperature Curves for 1880, 1881 and 1883.



The above data were taken from the records of the chronometer, without application of the effect of time, running in natural temperatures; the highest temperature for 1883, however, was obtained in the temperature room. The sets were selected by grouping the rates near the same temperature, the dotted lines showing the groups used, and the dots ⊙ × △, the mean rates and temperatures, each for ten days, during the time under comparison. The values of θ and z remain practically constant for 1880 and 1881, and change but little for 1883. A portion of this change may be attributed to the coefficient of time, which has not been considered.

r changes more or less with time in all chronometers, generally increasing if its sign is $+$, and decreasing if it is $-$. That is, from the time of cleaning, chronometers, as a rule, run faster as their age increases. This is especially so with new chronometers, which sometimes take two or three years to settle down to a steady rate. Not unfrequently do they gain, in the course of a three years' cruise, three or four seconds on the rates given them when issued. This change is gradual, and the daily acceleration or retardation is the coefficient of time.

Let T be the date at which the rate at a given temperature is r; T_1 any other date at which the rate at the same temperature is r_1; $T_1 - T = t$, the elapsed time, and g the coefficient of time.

Then
$$g = \frac{r_1 - r}{t} \tag{9}$$

And (1), the general equation of the chronometer, becomes
$$r' = r + z(\theta - \theta')^2 + gt \tag{10}$$

With No. 1262 Negus, from April 11, 1880, to April 21, 1881, $g = +.00067$; and from April 21, 1881, to April 17, 1883, $g = +.00204$. Owing to the change of θ and z the latter value of g was a little larger for temperatures above 70°, and a little smaller for temperatures below 70°.

In the ordinary uses of the chronometer for navigation purposes, the last term, gt, of equation (10), may be, and should be, omitted, as the value of g may change with time, and its use would indicate a greater degree of accuracy than would actually be obtained. Again, its value is always small, and the accumulated error from its rejection would come within the probable error of observation when ratings are frequent. It should, however, always be used in the establishment of longitude by meridian distances, and in other work where back calculations are made.

The temperature corrections should be used at all times, more especially when changes of temperature are frequent and extreme, and in making long voyages. A change of a few degrees in the higher or lower temperatures will change the daily rate one or more seconds, soon making the accumulated error amount to several miles in longitude. It is well to keep the chronometer record up for temperature even while lying in port, as it gives the navigator a knowledge of how it is running, and shows him what reliance he can place upon it at sea. By reference to Plate VIII, it will readily be seen what the effect would be on the rate of No. 1262 Negus were it rated in about 68°, and then taken into a temperature of either 55° or 80°, as often occurs.

Having determined the curve, on obtaining a rate at any subsequent time, if the rate does not plot on the curve, the difference will be a constant to be applied to all rates taken from the curve at different temperatures.

Great care should be taken when chronometers are suspended in their gimbals that they swing perfectly free, but without play enough to give them a jar; and the gimbals should be so adjusted that the chronometers will always hang with their faces level.

Nos. 725 and 1262 Negus, both running very regularly and adhering closely to their curves, were canted 9°, first with the XII down, then with the VI, IX and III down successively, leaving them two terms of seven days in each position, and placing them level again for two terms between the successive changes. They both lost on their level rates, varying from five-tenths to three seconds, and were more or less irregular; but when placed level again they each time came back to their regular rates, running a little irregularly at first.

Their mean rates reduced to a temperature of 70°, were as follows:

No. 725 *Negus.*

Face level, +0.72s; XII down, —2.18s; level, +0.77s; VI down, —1.27s; level, +0.78s; IX down, +0.17s; level, +1.01s; III down, —1.21s.

No. 1262 *Negus.*

Face level, +0.74s; XII down, —0.20s; level, +0.82s; VI down, —1.70s; level, +0.75s; IX down, —2.36s; level, +0.84s; III down, —2.65s.

The above changes are not excessive for chronometers slightly canted, and the cant is what would take place were the screws in one of the adjusting slots of the gimbals to become loose, allowing the bowl to slide to one side or the other.

At some time during the trial, after the chronometers have passed through the temperature test, and their curves have been determined, they are rated for one term of seven days each with the XII of their faces North, South, East, and West, successively, as a test for polarity; and should any evidences be found, they are again put through the different positions to make sure that the irregularities are not merely coincidences. Chronometers having actual polarity are at once rejected.

The chronometers are relatively placed after trial by the trial number, which is: Trial number $= (69° - \theta) + 1000\, z^2 + 10\, v^2$, in which 69° Fahr. is the temperature at which the chronometers should be compensated to have their fastest rates, and it is obtained by taking for a number of years the mean of the chronometer boxes of several vessels of the navy serving on different stations. z is the temperature-constant, and v the arithmetical mean of the five greatest variations of the mean rates from the curve as determined by formula (5).

$(69° - \theta)$ should in no case exceed 10°, except in chronometers compensated for special purposes, and it should be allowed to approach 10° only when z is very small, making the curve nearly a straight line. z should in no case exceed .006, and should be allowed to approach it only when $(69° - \theta)$ is very small, thus placing the large variations of rate, due to temperature, in the extremes to which the chronometers would seldom be subjected. v should in no case exceed 0.50s, making due allowance for coefficient of time, especially in new chronometors.

Chronometers failing to pass the required trial are returned to their makers, and rejected, if new and for purchase; but if old ones having been cleaned and repaired, they are to be recompensated free of charge and returned for a new trial.

Chronometers for service are selected with a view to the temperature in which they are to be used. Those for warm climates should have their point of compensation highest, and those for cold climates the reverse. Those to be used in both cold and warm climates should have their temperature-constant small; and in all cases the

smaller the value of z, the nearer the curve will approach a straight line and the better will be the chronometer, all other things being equal. On being issued, chronometers are transported by hand direct from the Observatory to their destination while still running, and are handled with the greatest care. For transportation they are taken from their gimbals, wrapped closely in paper and placed level in a basket of cotton, cushioned around the edges and from each other, but not tightly packed. They are delivered to the navigation officer of the navy yard or of the vessel, as the case may be, when the supervision of the Observatory ceases until their return. Their boxes are enclosed in the transporting cases, neatly crated and sent as freight.

In transportation the principal things to be guarded against are circular motion and placing them in any other position than a level one. If their error and rates are to be carried on in transportation, a maximum and mimimum thermometer should be packed in the basket as near as possible to the chronometers to obtain their mean temperature *en route*.

NAVAL INSTITUTE, ANNAPOLIS, MD.

FEBRUARY, 1884.

CHARTS AND CHART MAKING.

BY LIEUTENANT JOHN E. PILLSBURY, U. S. N.

The question of aids to safety in navigation is of great importance to a very large portion of mankind. The merchant who is interested in the vessel or the cargo ventures his capital; the passengers, who as a rule know the least of the dangers to be overcome, and who are obliged to have faith in the ability of the officers in charge and in their appliances, are risking their lives; and the officers, on whom the whole responsibility rests for the safety of the property under their charge, as well as for the lives of those on board, are staking their reputations as well as their lives every time they get underway.

Without a chart of some sort the question of navigation would be reduced to a matter of considerable difficulty and great hazard; and in this day of high speed, quick sales for early cargoes, increase of pleasure-travelling, and efforts for the repeal of compulsory pilot laws, it is imperative that the piece of paper on which are depicted the shore-line and contour of the bottom shall be as nearly true to nature as it is possible to make it, and should show everything that can in any way assist in bringing the vessel safely into port.

As a rule, from the beginning of chart-making, governments have assisted and fostered work of this kind; but it is only in comparatively recent times that governments have engaged in a systematic collection of data, and an embodiment of the data on well-digested schemes of charts embracing the whole world.

There may be some present who are not wholly familiar with the methods which are at present in use in the Coast Survey in preparing the charts for issue from the beginning. At the risk of repeating a story familiar to some, I would like to relate the various steps in chart-making for the benefit of the others. The primary triangula-

tion of our own coast has been practically finished, and the secondary triangulation nearly so. As the secondary triangulation is carried on, the topography is executed according to schemes drawn up by the Superintendent. The Hydrographic Inspector, in consultation with the Superintendent, receives directions as to the localities of the proposed hydrographic work, and then lays out the scheme of projections for each party according to the nature of the work. The draughtsmen in the office prepare the projections according to this scheme, and the chiefs of the hydrographic parties eventually receive them, together with descriptions of triangulation points, bench-marks and detailed instructions from the Hydrographic Inspector.

Upon the conclusion of the survey the projections are returned to the office, showing the fixed positions on all the lines of soundings, appropriately lettered and numbered, together with sounding-books, showing the soundings and times, and the angles taken with them; angle-books, showing the angles used to cut in hydrographic signals from the triangulation points; tide-books, showing the reading of the tide-gauge during the progress of the survey, and, lastly, sailing directions, or a description of points of interest developed during the work. Draughtsmen attached to the office of the Hydrographic Inspector then verify the positions, plot the soundings, and, after the finished sheet is registered, the draughtsmen of the drawing division make a reduction of it for the engraver, on the exact scale to be used for the finished chart, which is verified by the Hydrographic Inspector by comparison with the original. In the meantime a project has been decided upon, showing the limits of the proposed chart; the topography has been reduced and a plate has been prepared ready for the engraver. As a rule, engravers have two plates on hand at once, so that while one is being proofed, or is waiting for additional work, or is delayed from any cause, the other may be taken up and no time be lost. As the plate approaches completion in hydrography and topography, the magnetic variation is ascertained for the probable time of issue; the light-house table prepared, and the "aids to navigation" are obtained from the Light House Board, and the title and notes decided upon.

When the plate is finished it goes to the electrotype department to be duplicated. One plate will stand only about 1200 or 1500 impressions, and in order to save cost of reproduction by engraving, the original is duplicated for a printing-plate and then stowed away. The electrotyper first cleans the plate with potash,

then coats it with the thinnest possible film of silver to prevent the original from adhering to the alto. It is then placed in a frame in a vertical vat holding a solution of sulphate of copper, and is connected with a battery; copper is slowly deposited upon its face for a day or two. The deposit in a vertical vat is the result of very slow action and presents a smooth and even surface all over the face of the plate.

The plate is next placed in a horizontal vat, and the process of depositing the copper is proceeded with more rapidly. It is daily removed and weighed to ascertain the amount it has received, and the protuberances which form on the back are filed down to make a smooth surface. After a few days, when it has received a sufficiently thick coating, it is removed, and it then appears like a single, thick plate, as the deposit and the original plate are joined at the edges. The edges are filed and the plates separated, the deposit being in alto-relievo. The same operation is repeated, using the alto on which to deposit, and the result is an exact duplicate of the original.

About thirty pounds of copper are deposited for a large-sized alto, and fifty pounds for a basso. When the life of this basso is gone, the alto first obtained is used to produce another basso, and so on for perhaps five or six times, or until the alto is used up, when another strong one must be obtained from the unused original basso.

The question of fine printing is almost, if not quite, as important as that of fine engraving. It is almost impossible to obtain a plate of uniform thickness, and as the rolls of the printing press do not allow for irregularities, except to a small degree, the impress will show strong at the thick, and weak at the thin parts. The printer first lines up the rolls to the average thickness of the plate, and takes an impression. He then cuts out pieces of paper of the shape of the weak parts and puts them under the back of the plate, and runs it through again. This time it looks better, but he continues cutting out pieces and pressing up more and more upon the back of the plate at the faulty places, until he has a perfect proof. After the day's printing is completed, the charts are dried and then placed in a large press and subjected to a pressure of about two hundred and fifty tons, which takes out all the irregularities and forces the ink into the paper so that it will not readily rub in use.

Dry printing is impossible with an engraved plate, and wetting the paper is open to serious objection because of the shrinkage in drying. The paper supplied from France shrinks the least and also the

most regularly in all parts, the shrinkage being only 1 per cent. with the grain, and 1½ per cent. across; but this paper is of very short fibre and breaks and tears even with the greatest care, and it is very expensive. American paper shrinks unevenly, the shrinkage being about 1 per cent. with, and 2½ per cent. across the fibre; it is, however, better by far than the French paper for use at sea. Bond paper is the toughest and cheapest, but it shrinks so unevenly that it is not advisable to use it for any large charts.

I come now to the question, very important to the chart-maker, and more so to the navigator—that of doubtful dangers and positions. It may be said that, except along the coasts of the chief civilized countries, almost all positions are doubtful; and the dangers in mid-ocean whose positions or existence are not determined number thousands. Upon examining almost any general chart one is struck with the multitude of interrogation marks and other expressions of doubt; and upon examination of the data relating to these presumed dangers, one is astonished at the little knowledge we have of a vast number of them. Before the invention of chronometers, the early navigators, knowing nothing about currents and not reckoning their leeway accurately, obtaining their longitude only by their run, and their latitude by observations with the crudest instruments, have handed down to posterity the accounts of their voyages with remarks like the following: "Landed on the shore of a beautiful island, about 1000 leagues from the coast of New Spain, and in latitude by the sun of 20 degrees south." The latitude might be in error a degree at least, and the longitude half a dozen. Where the descriptions are full, later explorers have been able to recognize them. Some few, however, of those not recognized still have a place on comparatively late charts; in one instance, with the remark "Not seen since 1695." Coming down to more recent dates, when watches and poor chronometers were used, the positions given are of little value except to confirm the existence of a danger.

There are three prominent kinds of error that come to our notice: inaccurate observations, discrepancies in the longitudes of the charts of various countries, and typographical or clerical mistakes. I will here consider the second of these, discrepancies of longitude, leaving the first to be taken up later on.

The charts of the East India archipelago, by the British Admiralty, differed from those of the Netherland government, until within the last decade, by five or six, or in some instances by as much as ten,

minutes in longitude. Within the last three or four years, indeed, the charts of Gaspar strait, by the U. S. Hydrographic Office, differ from the British Admiralty by 1′45″, and from the Netherland charts by over 1′25″. A shoal reported in lat. 3° 00′ 00″ S., long. 107° 15′ 00″ E., was placed on the English chart S. 16°, E., 10 miles distant from Shoalwater island, and on our own S. 7°, E., 9¾ miles distant. A captain discovering a shoal takes bearings, pricks off its latitude and longitude from his chart, and sends the position to the nearest newspaper. At last it reaches the various hydographic offices and appears on one chart southeast of an island, on another south, and on a third still more to the westward. The Scoresby shoal was reported by a captain, who gave good bearings of prominent points which he said plotted on his chart within 30″ of his position by observation. Could we but find the chart he used we too might see the same; but unfortunately, on all authoritative charts, the bearings plot some eight miles away from the position by observation, and so the shoal appeared on our charts in both positions.

It sometimes happens, however, probably through neglecting to keep a systematic record in past years, that even where the position was given at which the chronometer was rated, the longitude of the danger has not been changed with that of the point on which it depended. The Dawson shoal in the Java sea was reported to be in latitude 4° 42′ S., and longitude 117° 05′ 15″ E., depending upon the east point of Pandita island, which was in longitude 115° 40′ 00″ E. The longitude of this island has been corrected to 115° 35′ 30″ E., but the shoal still remains on the charts in the position originally given. This shows the absolute necessity of a system of tabulated records, showing not only the longitude on which each danger depends, but also all the dangers whose positions depend on any prominent point of doubtful longitude. When a correction is made in the position of the primary, as in the case of Pandita island, if we refer to the record, all the secondary positions can be changed without leaving it to some chance investigator to discover the mistake.

Clerical and typographical mistakes cause many errors in the positions of dangers. These errors take the form of changed bearings and distances, wrong figures in geographical positions, and also wrong letters denoting the latitude and longitude. Bearings are reversed, so that instead of the island bearing northeast from the shoal, the shoal is placed northeast of the island. Errors often occur from a confusion of the Paris and the Greenwich

meridians; sometimes the difference of longitudes is entirely omitted. An instance of change in the designation of latitude may be mentioned in the case of the Marqueen or Cocos group. In Mr. Findlay's North Pacific Directory we read that Admiral Krusenstern applied the name of Mortlock to a group discovered by a Captain Mortlock, commanding the Young William in 1793, in about latitude 4° 45′ S., and longitude 157° E. In Findlay's South Pacific Directory we find similar mention, except that the date is given as 1795, and the position is slightly different. It seems hardly possible that the Admiral could have applied the same remarks and name to different groups in the same neighborhood, but in different latitudes. Another example of error in typography is shown in the case of a shoal in the Austral group. It was reported by its discoverer as being placed in about longitude 154° West, and it was carefully described. It was originally noticed in the British Nautical Magazine in the latter part of 1846. In one of the early months of the following year the French Annales Hydrographiques published the notice, but gave the longitude as 150° West (of Greenwich); and in both these positions it appeared on the French charts, and also on those of the British Admiralty. A few months later the British Nautical Magazine again published the information, but this time instead of 154° W. it gave 115 04′ W. as the longitude. That mistakes like these should be made seems strange, but it will be thought even more remarkable when I tell you that in each of these reports it was mentioned that the shoal was some two degrees to the WNW½W. of Remitera island, which, if the geographical position was omitted, would place it approximately in 154° West. The magazines published the reports evidently as so much printed matter, and not as correct nautical information on which the safety of a vessel might depend. No less than three French vessels have searched for the reported shoal in 150° West, their efforts prompted by this misleading information of the publishers of the magazines.

The government of the United States has been the unwitting cause of encumbering the charts with many danger-marks, which may be alluded to as examples of all kinds of errors. By an Act of Congress of August 18th, 1856, any American citizen who should discover an uninhabited island, rock, or key, on which was a deposit of guano, might enter into peaceable possession of it and be allowed to work it. Such island, rock, or key would then become the property of such citizen, and should pertain to the United States, &c.

Up to the year 1869, on the strength of this law, some seventy or more claims were presented and allowed, and so published to the civilized world. Some of these claims were taken from old charts, on which they had been placed by old whalers and others, in the most erroneous positions, the claimants probably never having visited the spots. Some of the locations were from more recent reports of poor navigators who, by careless observations, had mistaken a well-known island for a new discovery. A considerable number simply originated in the misplacement, chiefly by clerical errors, of islands from east into west longitude, or from north into south latitude, or the reverse. Many of the positions were those of perfectly well-known islands, inhabited in some instances by Europeans, and which never, as far as known, had been guano islands. Many were doubtless genuine discoveries, but most of them probably represented simply the claims of speculators who had ransacked charts, old and new, for islands on which guano might be found, hoping that in their own particular case fortune might favor them and bring gold to their coffers. Doubtless their lack of skill was only equalled by their want of principle, and so, in taking off the positions from the charts, they probably changed names and positions.

Another source from which incorrect reports of dangers come—let us hope, however, that the number is small—is the desire of incompetent, negligent, or careless navigators to escape punishment after running aground on a known danger, by reporting it as a new discovery in another position. The Cornelius Haga rock in Gaspar strait is, probably, an example of this. The vessel was lost, according to her captain's report, on a rock about five miles from Leat island, in the fairway, and the captain gave bearings to support his statement. The rock's position was placed on the charts, and many vessels were sent by the British, Netherland, and American governments to locate the danger. The expenditure of time and money must have been very great in hunting for this will-o'-the-wisp. At last the United States North Pacific Surveying Expedition learned from the natives that the wreck was *on* Leat island, instead of five miles from it, and upon examination it was found to be on a reef within a mile of the beach, and one of the anchors marked Haga was recovered. Another example was communicated to me by an officer now on duty here, who, while navigator of the Penobscot, was ordered to obtain a statement of the facts from a captain who said his vessel had struck on a rock in the Arcadine passage at the entrance to Port-au-Prince. On leaving the

ship, after receiving the captain's statement, he noticed a piece of bush hanging from the martingale-stay of the vessel, and as he was pulling away from the ship he quietly secured it. After searching the passage he pulled to the adjacent Arcadine islands, on the course the vessel had taken, and found that everywhere deep water could be carried up to the very beach; upon comparing the piece of bush with those on the island they were found to agree. It is probable that the vessel had run her head-booms into the bushes; but the captain, to save his insurance, and himself from blame, had wilfully falsified facts.

Discolored water is sometimes, though not always, excellent evidence of a shoal. Many patches of discolored water have been reported between the Kermadec group and the Australian coast; at least two surveying vessels, one English and one German, have found in this region many patches of animalculae, which may have given rise to the reports of shoals. One of these patches described by the German surveying vessel Gazelle had at a little distance a light green appearance, as if a shoal, but upon close examination was found to be composed of minute animals connected together, forming a string.

Breakers cannot always be considered as indicating shoal water. How many times in the experience of every officer who has stood a watch, has he been startled by what at first he thought to be a shoal with heavy breakers near the horizon, when there happened to be a heavy combing sea and the sun shone through the clouds occasionally. The sun shining on the crest of a wave, where all around is in the shade, will produce just such an effect, and this has without doubt been the cause of many reports of shoals by unreasoning or uninvestigating captains.

Of inaccurate observation, little can be said. Even the most careful observers may sometimes make mistakes of this kind. How much surveyors and other reliable authorities differ, even in the determination of latitude, will be seen in the consideration of Krakatoa island, which, lying at the southern entrance of Sunda Strait, has recently been submerged by an earthquake. Its peak has been placed by thirteen different observers, all, I think, naval officers, in the following latitudes, the minutes and seconds only being read: 12′05″, 08′00″, 10′00″, 10′09″, 08′03″, 09′00″, 07′00″, 03′00″, 09′42″, 07′59″, 07′10″, 09′11″ and 09′00″, the extremes differing 09′05″. With these differences in latitude, is it to be wondered that errors in the establishment of longitude occur? Yet these errors are at times

so great as to lead one to the belief that they are the result of mere guesswork. It is related of an old commanding officer in times gone by, that noticing on the chart what he thought to be a rock near which the vessel would pass, he told the navigator to have the course changed at once. The navigator replied, " I think, sir, there is not much danger in that rock," and with his handkerchief brushed from the chart the fragment of snuff that had fallen from the old gentleman's beard. We all wish that the charts could be as easily cleared of all doubtful dangers, and commanding officers as easily relieved from the many cares and doubts that they must feel when in their neighborhood. I have heard many adverse criticisms and objections raised against putting on charts these numerous doubtful reports. Many of the reported dangers, without doubt, have an existence only on paper. But who can tell without the strictest search which one shall be retained and which erased? It is a very easy matter to expunge a shoal from a plate ; but it may be rather difficult to explain to the captain who has wrecked his vessel on it afterwards that its removal was warranted on sufficient grounds. I would not advocate placing a new report on a chart without a probability that the danger referred to really exists, and that its position is approximately correct. But, once deemed of sufficient importance to be placed on a chart, it ought not to be removed until an exhaustive search has proved its non-existence with almost absolute certainty. The difficulty of proving beyond doubt that a shoal, even in a well-known harbor, does not exist, is very great, as can be shown by many examples. How much more difficult is it to determine this in mid-ocean! The Rodgers shoal in the China sea was searched for during four days, but, although the original report gave bearings of points on shore, and the boats sounded and swept with a chain all around the spot, no danger was found, until when the vessel was about to get underway, a ripple on the water close aboard was examined and found to be over the rock, almost exactly on the intersection of the bearings given. The vessel and her boats had been many times within a very few feet of the rock without having been able to discover any signs of it. The Brilliant shoal, in about latitude 23° south and longitude 170° east, was discovered in 1847 and located. Captain Durhan, R. N., made a careful search for it, running many lines over a surface sixty miles in diameter about the position, without being able to discover any signs of shoal water, although sounding with 250 fathoms of line. This

was thought to be conclusive evidence of its non-existence, and the British Admiralty expunged it from their charts. It was not long, however, before a French and an English vessel reported it as very near the original position given. It was replaced on the chart, and no doubt was expressed as to the fact of its existence and the correctness of the location. Recently, another English vessel has searched for it, but without success, and again it is marked "Position doubtful." Even on our own coast, within the past year, in Long Island sound, a rock has been discovered having over it 10½ feet of water. It was searched for during many days without success; but finally it was discovered when, on getting underway, the centre board of the surveying schooner grazed its surface.

There are many instances where examinations have been made, and the shoal expunged on evidence of non-existence, derived from careful search over large extent of surface, and from frequent soundings with deep-sea lead in two and three hundred fathoms of water. The evidence, as far as the lead is concerned, is really of not much value when we remember how abruptly rocks rise from great depths. The Coast Survey steamer Blake found depths of over 2000 fathoms within 2½ miles of the Bahama banks; and in some places on the line of soundings the inclination was 45°. Small pinnacles are often met with inshore, and sometimes with such inclination that the lead will not rest on their surfaces. One instance of this is met with near Armstrong bay, on the south coast of Australia. The pinnacle has only one fathom over its apex, and presents so small a surface to the waves that the sea rarely breaks thereon, and the lead finds no resting place. Cases of submersion or subsidence are sometimes found. The Gorringe bank was originally reported as having 3½ fathoms of water; but the Gettysburg found 32 fathoms to be the least depth. Broken coral and shells and well-rounded pebbles were brought up, indicating that erosive wave-action had at one time exercised its influence on the summit of the shoal. The Hunter island was reported to have been situated in latitude 15° south, and in about longitude 166° east. It was described as of volcanic origin, well-peopled and cultivated, corresponding in most particulars to the island of Nui-fu, situated in about the same latitude, but in 176° west longitude. Many searching parties have been sent to look for it, but without success; two or three years since, the British Admiralty issued a notice that probably the two islands mentioned were identical, Hunter island having, through a typographical error, been transferred from west to east longitude.

I think it probable, however, that the island has sunk beneath the sea. The searching parties have found two or three shoals near its reported position, and one part of the original description of the island is so unique as to throw a doubt on the validity of the conclusion of the British Hydrographic Office. The little fingers of the left hands of all the inhabitants had been cut off at the second joint, and their cheeks were perforated. The first is a remarkable peculiarity that would undoubtedly attract the immediate attention of explorers, but nowhere else can I find mention of this maiming of the hand.

As to the best method of searching for dangers, I can offer no new ideas. There is no improvement upon the old plan of running on ranges, having one or more buoys ready to drop at a moment's notice. In deep-sea searching, the wire-sounding apparatus of Sir William Thompson, and that of Commander Sigsbee, are acknowledged by all to be not only useful as auxiliaries, but also *absolutely necessary*, if valuable results are to be expected. When a shoal is found it should, if possible, be examined from a boat. Even if the boat cannot go over the shoal, it can go near enough to be sure that the discoloration is not due to the presence of animalculae, or to breaking water carried on by the tide or currents. If the breakers are small, the boat can pull close around them and ascertain at once if there is an extension of the danger, a service that the ship could not satisfactorily perform on account of her greater draught. If time can be spared it would be well to take, not a single set of observations, but a series of sets on both sides of the meridian, or a series of three or four twilight observations, for Summer's lines. In the report, the officer should state definitely the point on which the chronometer errors depended, both before and after the discovery.

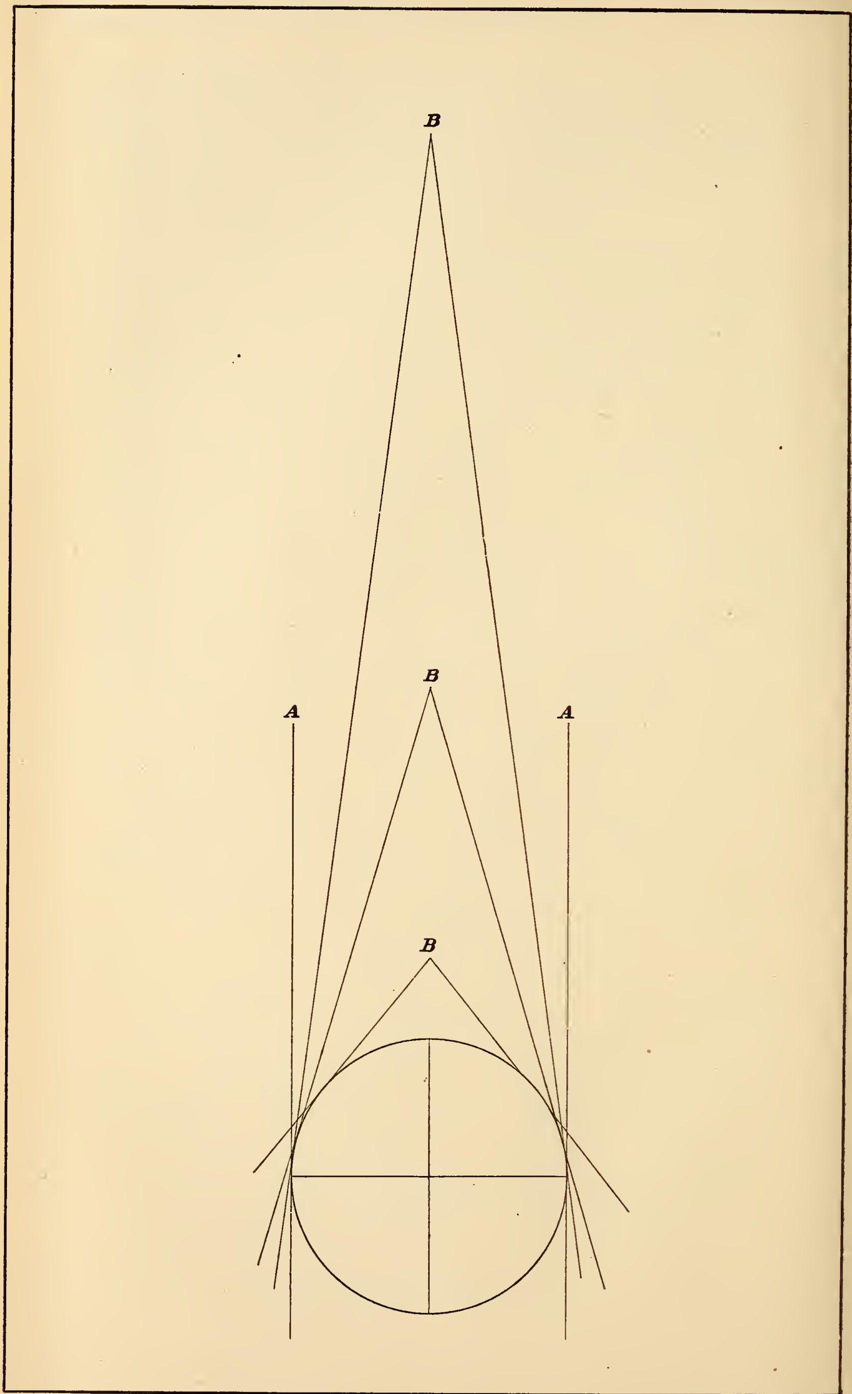
The Mercator projection for the construction of charts is the one in general, and I may say, almost universal use. It possesses an advantage which is deemed by most seafaring men an essential to a chart; any straight line drawn makes the same angle with all meridians. It has on the other hand no two consecutive miles of the same length, except on the parallels. The rhumb-line represents a part of a spiral, or practically a small circle of the earth. For a chart of the world, or for long distances, it is probably better to use Mercator's projection; but for small extents of surface, say 10 or 15, or at most, 20 degrees of longitude, the polyconic projection is far preferable, for the following reasons: 1st. It distorts to a less degree the configuration of the land or bottom; 2d. It has a scale

which may be taken from any point, on any meridian (preferably the middle one), and which may be used on any portion of the chart; and 3d. On the polyconic projection, a straight line is almost exactly part of a great circle of the earth; and by sailing on it we travel on the shortest possible line between the two points.

There are many objections named to the polyconic projection, and some of them I will mention. Recently, a commanding officer in the Gulf of Mexico noticed, I suppose for the first time, a chart on the polyconic projection. He was bound to New Orleans, and, calling his navigator, he asked how it was that the chartmakers could have made such a mistake as to curve the parallels. Another objected because he could not lay out a course on it with confidence, fearing every time that his landfall would be miles away from his port. Another said he could not plot a bearing to a distant peak, because the projection was curved and his bearing would be straight, forgetting that his line of vision was a straight line and followed in the plane of a great circle, and that on Mercator's projection all lines, except the meridians and equator, represent small circles of the earth. Another objected to this unwelcome innovation because he could not plot a position with a parallel ruler from the margin of the chart; and another, because he was accustomed to Mercator's projection. I suppose I have heard scores more of as reasonable objections, and probably you all have heard similar ones. If we are always to adhere to what is old, out of respect to the wisdom of our fathers, we shall never improve; but, perhaps, in future generations, when pounds, shillings, and pence, and ounces and pounds, are things of the past, eleven and a quarter degrees to a point of the compass will have gone too; and men who go to sea will not be afraid to use a chart simply because it is on the polyconic projection.

Without going into minute details, the simple conic projection is this: Imagine a cone surrounding the globe, its apex coincident with the earth's axes produced, and its surface tangent at any given middle parallel. Upon developing the cone, this parallel will be the arc of a circle having a radius equal to the slant side of the cone from the apex to the point of tangency. Parallels are struck from the same centre, and the meridians are straight lines. It will be seen that the lengths of the degrees of latitude are true. The degrees of longitude are in excess of the true below the middle parallel, and are less than the true above the parallel.

There are many modifications of this projection, the most valuable


B
B
A
A
B

of which are those of Bonne and those of Professor F. R. Hassler. In the former, the parallels are divided off from the middle meridian into parts the same as on the sphere, and through corresponding divisions the meridians are drawn. Lines on the sphere appear nearly the same on the projection, and the same scale may be used in all parts of the chart not exceeding a few degrees in extent. In the polyconic projection, instead of one tangent cone being used, there is one for every parallel, and, theoretically, an infinite number. Each parallel is therefore independently developed; but, on this chart also, the parallels are divided into the same proportional parts as on the sphere. A glance at the figure (1) will show the differences in the Mercator's, the Bonne's, and the polyconic projections. The Mercator's is projected to the cylinder *A*, tangent at the equator. Bonne's is projected to any one of the cones *B*, which are to be tangent at the middle latitude, and the polyconic is projected on the cones *B*, *B*, *B*, each tangent to successive parallels. At the equator the cone would have infinite altitude; hence, its sides become practically parallel. The effect of this projection to successive cones of different altitude is, upon development, to make the parallels of latitude curves; but the curves in a chart of the Gulf of Mexico, for instance, on a scale of $\frac{1}{1200000}$, will hardly be perceptible in short distances. The actual amount of separation between parallels 13° apart, measured at the edge of the chart, and in the centre at intervals of 10° of longitude, is eight miles, or only about two-thirds of a mile to a degree. This is so slight that the parallels may be called and used as truly parallel in a chart of this size.

The first advantage I named was that the polyconic projection distorts the least of all. This would seem to be true as shown from the figure, for the greater the angle of deflection of the plane on which the projection is thrown, the greater the distortion; as the setting sun will throw lengthened shadows, while a noonday sun throws true ones. On this projection the meridians are divided into an even number of proportional parts of the surface of the earth; that is to say, a scale of $\frac{1}{40000}$ means that one inch of paper equals 40,000 inches of the earth's surface; and as minutes of latitude are practically miles (and would be exactly equivalent if the globe were a perfect sphere), the subdivisions of any of the meridians are practically miles, and may be used as such taken from any part of the chart. To be exact, the distortion is least and the scale is truest on the middle meridian cut. The subdivisions of the parallels are minutes of longitude.

A chart on the polyconic projection of $\frac{1}{1200000}$ scale, or one foot of paper to 1,200,000 feet of the surface of the earth, including within its limits ten degrees of longitude, has its parallels at the central meridian, seven miles (in the latitude of Cape Henry) below the straight line joining the extremities of the parallel. This straight line disagrees with the great circle course on the surface of a sphere by less than *ten minutes* of azimuth taken at any point on it. On a Mercator's projection in the latitude of Cape Henry, on an east course, the difference is *two degrees and twenty-four minutes*, and on a northeast course nearly *two degrees* (Plate 2). For longer courses than this the straight line on the polyconic projection would still closely approximate to the true great circle; while on Mercator's projection, the longer the course the greater the error.

It would be very convenient to be able to lay off a course and feel sure that if you hold it you will arrive at the desired port, *other things not interfering*, even if you do take a little longer time and go a little further; *but other things do interfere*, and the course has to be changed daily, or perhaps oftener. In parts of the Atlantic, on our own coast, where the variation changes over half a point in a day's run, as between Cape Hatteras and Nantucket, a captain in a hurry, or one who believes in going by the shortest route, would probably change his course at every quarter point change of variation. Lay down a straight line on the polyconic projection, and that line is almost a true great circle. The initial course is the angle at which the course cuts the magnetic meridian at that point. After proceeding about seventy-five or one hundred miles the variation has changed, and you are a quarter of a point off the course in consequence, and also on account of the angle between the meridians, which is, in this distance, equal to about one degree. You change the course then, and continue changing as often as may be necessary to keep the line, and you will have practically sailed over a great circle. Upon a Mercator's chart also the courses can be regularly changed and the vessel made to traverse a great circle; but it is necessary that the circle shall be previously plotted, and for every deflection a new course must be computed or laid off; while on a polyconic chart, a great circle is obtained whenever a straight line is drawn.

As a matter of curiosity I show on Plate 2 a line that a vessel would follow by holding an east course and by neglecting to make allowance for changes in variation. The vessel will arrive upon a given meridian at a distance of about thirty miles north of the point which would have

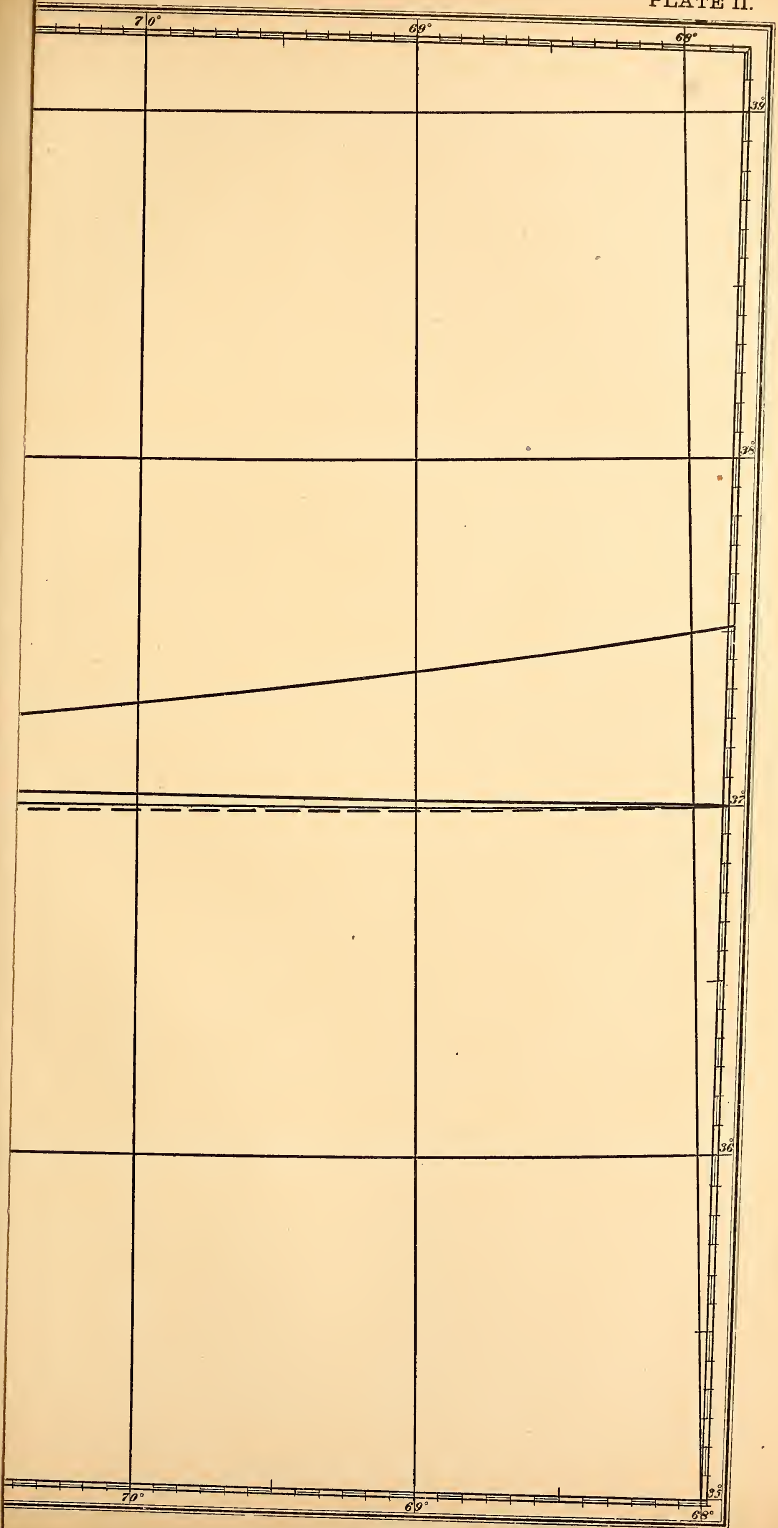

70°
69°
68°
39°
38°
37°
36°
35°
70°
69°
68°

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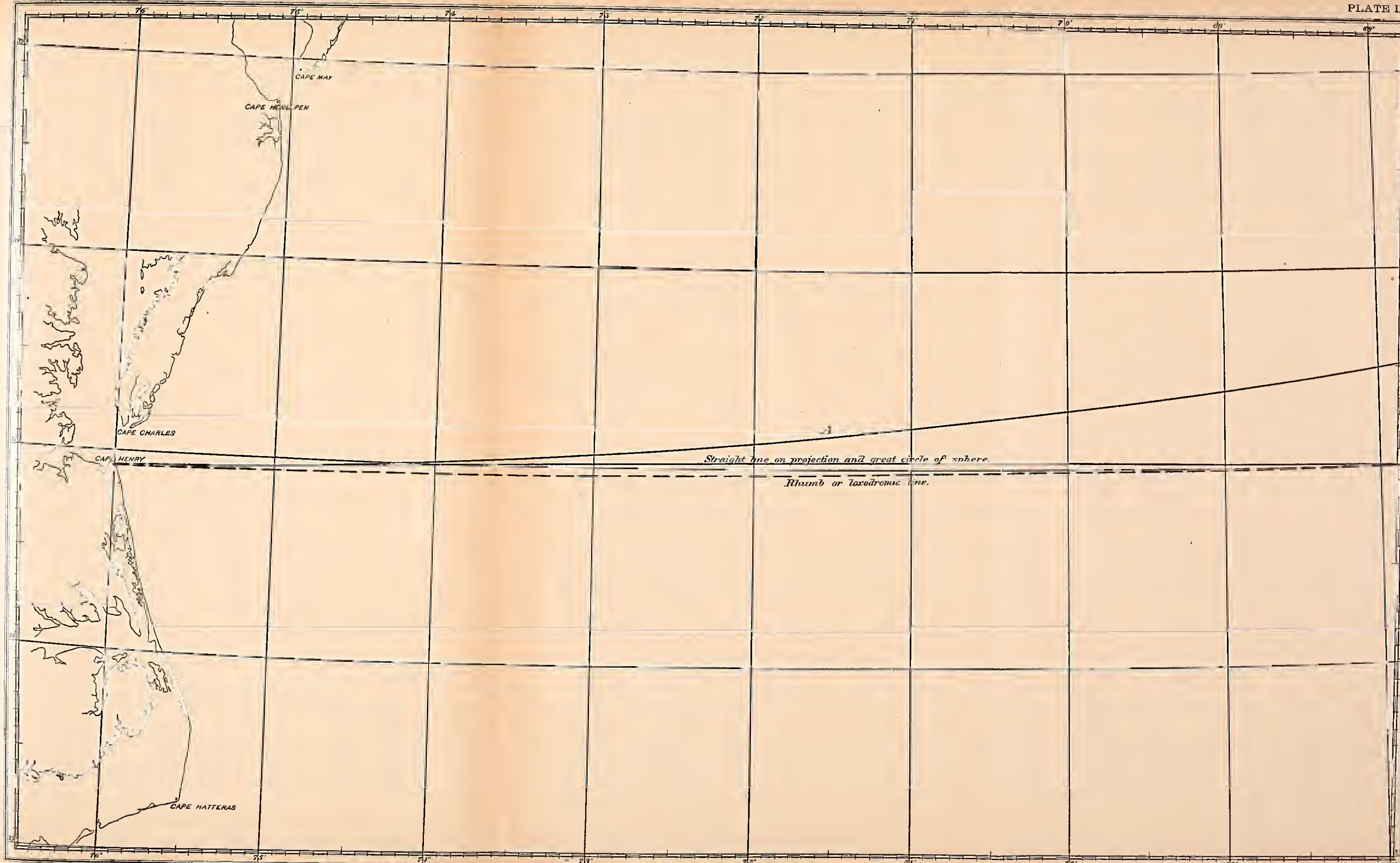
PLATE II.



CAPE MAY
CAPE HENLOPEN
CAPE CHARLES
CAPE HENRY
Straight line on projection and great circle of sphere.
Rhumb or loxodromic line.
CAPE HATTERAS

been reached had allowance been made for the changes in variation. To make a fair day's run and reach a given point requires a careful study of the changes in the variation, if one course only is to be steered. Approximately, however, the mean of the variation will frequently answer for a single day's run. In the case before us, by the use of the mean variation we shall reach a point only four and a half miles south of our objective point in a run of three hundred and eighty miles. This discrepancy is owing to the irregularity in the change of variation.

The operation of taking a course from a compass card is exactly the same on both of the charts in question, but with the advantage on the side of the polyconic, for as I have before stated, the new line is practically a great circle. In actual practice, running on an east course in this latitude, I would change every hundred miles if I wished to make a good passage; if not, I would lay one course, using the middle compass.

In plotting a position, it is but little work to lay off the latitude on the nearest meridian, and then, with dividers for the longitude, and a parallel ruler, the position may be plotted with greater accuracy than by laying it off at a long distance with the rulers, as on a Mercator's chart. It seems, then, that as far as accuracy and convenience in navigating are concerned, the polyconic chart is better, within small limits, than the Mercator's; as regards convenience, a strong point in favor of this projection is, that, in measuring we are able to take distance from the subdivisions on the meridians at any point on the chart, instead of carefully adjusting for the middle latitude (sometimes applying a correction), as on the Mercator's.

The question naturally arises, If this projection is considered best for charts of limited extent, why not for large ones?—and if not best for large charts, what is the greatest limit advisable? Plate 3 shows a chart on this projection of a portion of the Atlantic on a scale of $\frac{1}{5000000}$. The great-circle course, the straight line, and the rhumb-line are shown from Cape Hatteras to the English Channel. The great-circle course is only about forty miles distant from the polyconic straight line at its middle point, and nearly four hundred miles from the rhumb. It will be noticed at once that the parallels are curves, and that the meridians converge toward the top; but a close examination will reveal the fact that the meridians, except the central one, are also curves. An examination of this chart will show why it is that only limited areas should be represented on the polyconic projection. It

will be seen that the 10 degrees each side of the middle meridian do not vary much in scale, and for that distance the minutes of latitude measured on any meridian will not disagree with those of any other by more than $2\frac{1}{2}$ minutes in 10 degrees; and any distance may be measured in any direction without an error greater than this. When we go farther from the middle meridian the disagreement of minutes of latitude is greater, as shown by the following measurements, beginning from 34° latitude: at 10° from the middle meridian the disagreement in 10° of latitude is 02′ 30″; 20° from the middle meridian the disagreement in 10° of latitude is 22′ 00″; and 30° from the middle meridian the disagreement in 10° of latitude is 50′ 00″. The great-circle course shown is 3064 miles. The polyconic straight line, measured by using the meridians, separated 30 degrees from the middle meridian, is 3007 miles long, and 3227 miles long by using the middle meridian. It is this distortion in scale between extended limits which makes it unadvisable to use the polyconic projection as a sailing chart.

There is another projection, however, which supplies the place of a great-circle sailing chart, and it is very satisfactory, as far as the great circle is concerned. I refer to the Gnomonic. This projection is one that uses a plane tangent at a central point, the eye being situated at the centre of the earth. All straight lines on it are great circles, but the scale of distances is as complicated as one formed for the polyconic chart would be, and is probably more difficult to use. As this difficulty is common to both charts, the Gnomonic is the best to use for a sailing chart, because it has this advantage, that the straight line is a great circle, while on the polyconic chart it only approximates to one. In my opinion, charts on this projection should be issued to naval vessels, not as an absolute necessity, for the course can be calculated, but as a labor-saving appliance which would be found very useful in making long voyages.

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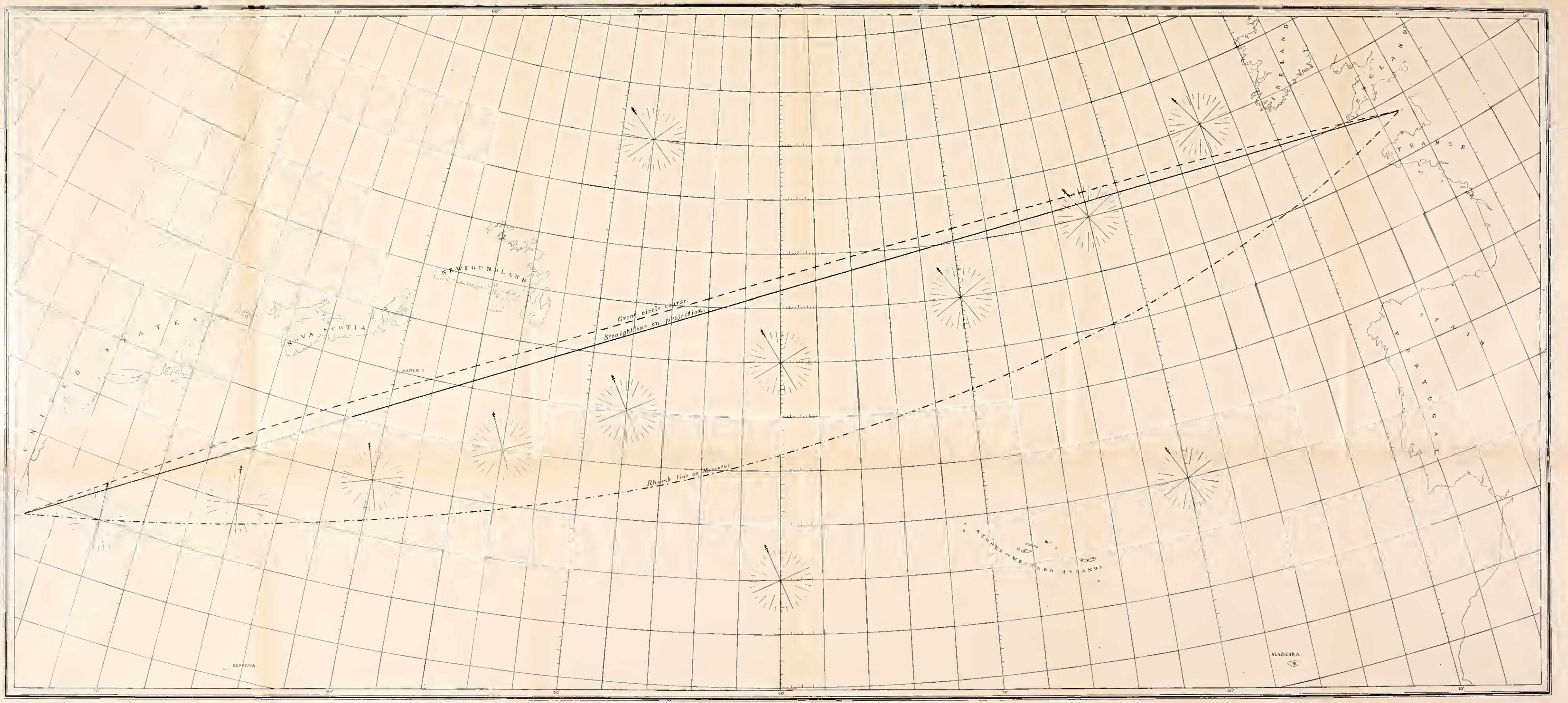
NORTH ATLANTIC OCEAN POLYCONIC PROJECTION



NAVAL INSTITUTE, ANNAPOLIS, MD.

FEBRUARY, 1884.

NOTES ON THE LITERATURE OF EXPLOSIVES.*

By Prof. Charles E. Munroe, U. S. N. A.

No. VI.

In No. V of these Notes we have referred to Berthelot's lectures on Explosives. These have now been reprinted by Van Nostrand as No. 70 of his *Science Series*. We then proposed to present later his discussion of the theories suggested to account for explosions induced by the influence of contiguous explosions, and hence we extract the following.

In discussing the duration and speed of propagation of explosive reactions Berthelot has regarded the development of the explosive reactions either from the point of view of their duration in a homogeneous system in which all the parts are maintained at the same temperature, or else from the standpoint of their propagation in a system equally homogeneous, to which fire is applied directly by means of a body in ignition, or else by a violent shock. In these later years, however, the study of explosive substances has revealed the existence of another method of propagating the reactions from an explosive centre, this propagation taking place at a distance and by the intermediation of the air or certain solid bodies which do not themselves participate in the chemical change.

We shall now speak of what are called explosions by influence, whose existence was formerly suspected from certain known facts connected with the simultaneous explosion of several buildings separated by considerable space from each other, as in catastrophes

* As it is proposed to continue these Notes from time to time, authors, publishers and manufacturers will do the writer a favor by sending him copies of their papers, publications or trade circulars.

occurring in powder mills. Attention has been especially directed to this class of phenomena by the study of nitro-glycerine and guncotton.

We will begin by giving the most important characteristic facts. A dynamite cartridge made to detonate by means of a fulminate cap causes the adjoining cartridges to detonate, not only by contact and by direct shock, but even from a distance. In this way an indefinite number of cartridges, arranged in a regular course, may be made to detonate.

The distances to which the explosion may be propagated are relatively great. Thus, for instance, with cartridges contained in rigid metallic envelopes and placed on a resisting soil, the detonation produced by 100 grams of Vonges dynamite (75 per cent. of nitroglycerine and 25 per cent. randanite, which is very finely divided silica) communicates itself 0.3 meter, according to the experiments of Captain Coville. D being equal to the distance in meters and C the weight of the charge in kilograms, the experiments of this officer show that $D = 3.0C$. When the caps were laid on a rail D was found to be equal to $7.0C$. On soft or ploughed-up earth the distances, on the contrary, are less. When a cartridge is suspended in air there is no detonation by influence, perhaps because the cartridge not being fixed can recoil freely, which diminishes the violence of the shock. Nevertheless there are experiments which show that the air suffices for the transmission of the detonation by influence, although with greater difficulty and requiring a greater mass of the explosive. With a dynamite less rich in nitro-glycerine (55 per cent. of nitro-glycerine and 45 per cent. of the argillaceous ashes of boghead coal), contained in similar cartridges, and placed along the ground, the experiments of Captain Pamard have given the smallest distances: $D = 0.90C$. If metallic envelopes having less resistance are used, the distance at which the explosion is propagated is likewise diminished. Dynamite simply spread along the ground ceases to propagate the explosion. The experiments performed in Austria have given similar results. They have shown that the explosion is communicated either in the free air with intervals of 4 cm., or else through pine boards 18 mm. thick. In a lead tube with a diameter $= 0.15$ meter and a meter in length, a cartridge placed at one extremity has caused the detonation of a cartridge at the other end. The explosion is still better transmitted through tubes made with wrought iron. The couplings of the tube diminish its aptitude for transmission.

An explosion which is propagated in this manner will go on weakening itself from cartridge to cartridge and even change its character. Thus according to the experiments made by Captain Müntz at Versailles, in 1872, a first charge of dynamite exploded directly, excavated a funnel-shaped hole in the ground with a radius of 0.30 meter; the second charge, detonated by influence, produced an opening of only 0.22 meter; the effect of the detonation was then reduced. This reduction should manifest itself towards the limit of the distance at which the influence ceases. In the same way four tin screens were located 40 mm. apart, a small cylinder of gun-cotton was placed against each of them, and the entire affair arranged on a board; 15 mm. in front of the first screen a similar cylinder was detonated. All of the cylinders detonated, but a progressive diminution was observed in the indentations produced in the board below each cylinder. According to these facts the propagation by influence depends at the same time on the pressure acquired by the gas and on the nature of the support. It is not even necessary that it should be rigid.

Finally, in operating under water at a depth of 1.30 meters, a charge of 5 kilograms of dynamite brought on an explosion of a charge of 4 kilograms situated at a distance of 3 meters. The water then transmits the explosive shock, at least to a certain distance, as does a solid body. This transmission is so violent that the fish are killed in ponds within a sphere of a certain radius by the explosion of a dynamite cartridge.*

Similar experiments have been made by Abel with compressed gun-cotton. According to his observations the explosion of the first block determines that of a series of similar blocks. The propagation under water has likewise been studied; the explosion of a torpedo charged with fulminating cotton caused the detonation of adjoining torpedoes placed within a certain radius of activity. The sudden pressure transmitted by the water when measured by means of the compression of lead at different distances, such as 2.50 m., 3.50 m., 4.50 m., 5.50 m., goes on decreasing, as would be expected. Besides, experiment has shown that the relative position of the charge and of the "crusher" is of no consequence, which is in harmony with the principle of equal transmission in all directions of hydraulic pressures.

* For further data, see Abbot's Submarine Mines, pages 54 and 122.

Explosions of fulminating substances which are rapidly propagated to a great number of caps, belong to this same order of explosions by influence. We have previously cited the explosion in the Rue Beranger.* The experiments which M. Sarrau made on that occasion showed that caps of the description which produced this catastrophe may be successively burned in a fire without giving rise to a general explosion; whereas the explosion of a few of these same caps, each containing 10 milligrams of explosive material, if it is provoked by a rapid pressure, determines by influence the explosion of the adjoining packages, even when they are not contiguous and are situated at a distance of 15 centimeters apart. A general explosion may thus easily be produced by influence. It follows then from these facts, and especially from the experiments made under water, that the explosions by influence are not due to inflammation, properly so called, but to the transmission of a shock arising from the enormous and sudden pressures produced by the nitro-glycerine or the gun-cotton.

Let us enlarge upon this explanation; it is the same fundamentally as that which we have already shown as accounting for the influence of the shock which determines the direct detonation of explosive substances.

In an extremely rapid reaction, the pressures may approach to the limit which corresponds to the matter detonating in its own volume, and the commotion due to the sudden development of almost theoretical pressures can be propagated both through the ground and supports as intermediary, or through the air itself, projected *en masse*, as has been shown by the explosion of certain powder factories and of gun-cotton magazines, and even by some of the experiments with dynamite and compressed gun-cotton. The intensity of the shock propagated either by a column of air or by a liquid or solid mass varies with the nature of the explosive body and its mode of inflammation; it is of greater violence according as the length of the chemical reaction is shorter and develops more gas, that is to say, a higher initial pressure, and more heat, and consequently work, for the same weight of explosive material.

This transmission of a shock is conveyed better by solids than by liquids, better by liquids than by gases; with gases it becomes better as they are more compressed. Through solids it is better propagated according to their degree of hardness, iron transmitting

* Nav. Inst. Proc. 9, 752.

it better than earth, and hard ground better than ploughed soil. All breaks of continuity in the transmitting material tend to weaken it, especially if a softer substance is interposed. Thus it is that the use of a tube made from a goose-quill, as a receiver, stops the effect of mercury fulminate, while a tube or a capsule of copper transmits this effect in all its intensity. The explosion by influence is the better propagated in a series of cartridges according as the envelope of the first detonating cartridge is the more resisting, which allows the gases to attain a greater pressure before the covering is destroyed. The existence of an empty space, that is to say, filled only with air, between the fulminate and the dynamite, on the other hand diminishes the violence of the shock transmitted, and in consequence that of the explosion; generally the effects of breaking powders are lessened when there is no contact. To form a full conception of the transmission of sudden pressures which produce shock by the supporting medium, it is desirable to recall this general principle, in virtue of which, in a homogeneous mass, pressures are transmitted equally in all directions, and are the same on a small element of surface whatever its position. Detonations produced under water with gun-cotton show that this principle is equally applicable to the sudden pressures which produce the explosive phenomena. But it ceases to be true when one passes from one medium to another.

If the inert chemical matter which transmits the explosive movement is fixed in a given situation on the surface of the ground, or better, on the surface of the rail on which the first cartridge was placed, or better still, held by the pressure of a mass of deep water in the midst of which the first detonation is produced, the propagation of the movement in this matter will hardly be able to take place, except under the form of a wave of a purely physical order, and consequently of an essentially different character from the first wave of a chemical and physical order simultaneously developed in the explosive body itself. This new wave propagates the concussion away from the explosive centre all around it, and with an intensity which decreases inversely as the square of the distance. Even in the neighborhood of the centre, the displacements of the molecules may break the cohesion of the mass and disperse it, or crush it by enlarging the chamber of explosion, if the operation is conducted in a cavity. But at a very short distance (the magnitude of which depends on the elasticity of the surrounding medium) these movements, confused at the beginning, arrange themselves in such order as to produce a wave,

properly so called, characterized by compressions and sudden deformations of the material, the amplitude of these oscillations depending upon the magnitude of the initial impulse. They move with a very great rapidity, and preserve their regularity up to the point where the medium is broken; then these compressions and sudden deformations change their nature and are transformed into a movement of impulse, that is to say, they reproduce the shock. If then they act on a new cartridge they may determine its explosion; the shock will be otherwise weakened by the distance, and in consequence the character of the explosion may be modified. The effects diminish in this manner up to a certain point from which the explosion ceases to produce itself. When this occurs on a second cartridge the same series of effects will be produced from the second to the third cartridge; but they depend on the character of the explosion of the second cartridge. And thus it goes on.

Such is the theory that appears to me to explain explosions by influence and the phenomena which accompany them. It depends, definitely, on the production of two orders of waves: one series represents the explosive waves, properly so called, developed in the midst of the matter which detonates, and consists of a continually reproduced transformation of the chemical actions into thermal and mechanical actions, which transmit the shock to the support and to the contiguous bodies; the other is a purely mechanical and physical series, which transmits equally the sudden pressure all around the centre of the concussion to the adjoining bodies, and by a singular circumstance to a new mass of explosive material.

A theory differing from this was originally proposed by Abel. It is the theory of *Synchronous vibrations*. According to this English savant the originating cause of the detonation of an explosive lies in this synchronism between the vibrations produced by the body which provokes the detonation and those which the first body would produce in detonating, precisely as a violin string resounds at a distance in unison with another vibrating chord. Prof. Abel has recited the following facts in support of his theory. To begin with, the detonators appear to differ with each variety of explosive. For instance, nitrogen iodide cannot cause the detonation of compressed gun-cotton. Nitrogen chloride will not produce the same detonation except when ten times as much weight is used as of the fulminate necessary. Likewise nitro-glycerine will not produce a detonation in sheets of gun-cotton on which is placed a case containing nitro-glycerine. In

this way nitro-glycerine up to 23.3 grams can be detonated without effect. On the other hand, 7.75 grams of compressed gun-cotton have caused the detonation, at a distance of 25 mm., of nitro-glycerine wrapped up in an envelope of thin sheet-iron. Likewise, according to Brown, a cap filled with a mixture of potassium ferrocyanide and potassium chlorate will not detonate gun-cotton. Finally, according to Trauzl, a cap consisting of a mixture of mercury fulminate and potassium chlorate should be of much heavier weight than if it be filled with the pure fulminate; nevertheless, the heat given off by the same weight is greater by one-fifth with the first mixture.

Messrs. Champion and Pellet have brought to the support of this ingenious hypothesis the following experiments: They attached to the strings of a double bass particles of nitrogen iodide, a substance which detonates on the slightest friction. Then they made the strings of a similar instrument vibrate at a short distance off; a detonation was produced, but only for sounds higher than a certain note which corresponds to 60 vibrations per second. They also took two conjugate parabolic mirrors, placed 2.5 meters apart, and they arranged along the line of the foci at different points several drops of nitro-glycerine or of nitrogen iodide; they then detonated at one of the foci a large drop of nitro-glycerine; they observed that the explosive substances placed in the conjugated foci detonated in unison, to the exclusion of the same substances placed at the other points. A layer of lamp-black placed on the surface of the mirrors was designed to prevent the reflection and the concentration of the heat-rays.

As yet none of the experiments appear to me to be conclusive, and several of them seem even to be directly opposed to the theory. We shall begin by observing that the characteristic feature of a given musical note, capable of determining each variety of explosion, has never been established. It is only below a certain note that the effects cease to be produced, while they take place by preference, whatever the explosive bodies may be, by the action of the most acute notes. Besides, these effects cease to produce themselves at distances which are incomparably less than the resonance of the chords in unison, which goes to prove that the detonations are functions of the intensity of the mechanical action, rather than of the character of the determining vibration. Similarly, the detonation ceases to be produced when the weight of the detonator is too slight, and in consequence when the mechanical energy of the shock is weakened. Nevertheless, the specific vibratory note which determines the ex-

plosions should always remain the same. For instance, cartridges filled with 75 per cent. of dynamite cease to detonate when the capsule contains a weight of fulminate less than 0.2 gram, the detonation only being assured in all cases by the regulation weight of one gram. This confirms the existence of a direct relation between the character of the detonation and the intensity of the shock produced by one and the same detonator.

If it is true that gun-cotton will cause the nitro-glycerine to detonate in consequence of the synchronism of the vibration communicated, then we do not understand why the reciprocal action does not take place; while the absence of reciprocity can be easily explained by the difference of the structure of the two substances which plays so important a part in the transformation of the mechanical energy into work.

This same diversity of structure and the modifications which it introduces into the transmission of the phenomena of the shock and the transformation of the mechanical energy into thermal energy, may be cited to explain the facts observed by Abel.

The difference between the energy of pure fulminate and of the fulminate mixed with potassium chlorate is no less easily explained; the shock produced by the first body being sharper on account of the absence of all dissociation of the product (which is no other than carbon monoxide), this absence should be contrasted with the dissociation of carbon dioxide formed in the second case. Perhaps, also, the formation of potassium chloride disseminated through the gas produced, with the concurrence of potassium chlorate, weakens the shock, just the same as silicon does in the case of dynamite.

All the effects observed with nitrogen iodide may be explained by the vibration of the supports and by the effects of rubbing which result therefrom, this substance being particularly sensitive to friction. The experiment with the conjugate mirrors may also be easily explained by the concentration in the focus of the movements of the air, and therefore of the mechanical effects which result.

Besides, M. Lambert has proved by experiments made for the Commission on Explosive Substances, that in the explosion of dynamite cartridges in tubes of cast iron of large diameter, regarded from the standpoint of detonations by influence, there does not appear to be any difference between the ventral segments and the nodes characteristic of the tube.

Desiring to clear up this entire question by removing it from the influence of the support and of the diversity of cohesion and physical

structure of solid explosive substances, I undertook a series of special experiments on the chemical stability of matter in sonorous vibration, and especially on that of gaseous bodies such as ozone, hydrogen arsenide, or liquids such as hydrogen peroxide and persulphuric acid, all of these bodies being selected from among those which decompose or change spontaneously at ordinary temperatures with the disengagement of heat, precisely as explosive substances do. The description of these experiments may be found in the *Comptes Rendus* or in the *Revue Scientifique*, May, 1880.

They lead to the conclusion that substances, which are transformable with the disengagement of heat, are stable under the influence of sound waves, while they are decomposed under the influence of ethereal vibrations. This diversity in the mode of action of the two classes of vibrations is not surprising when we consider that the most acute sonorous vibrations are incomparably slower than the luminous or thermal vibrations.

Hence it appears certain that the propagation of explosions by influence is not made in virtue of an undulatory movement, which is a complex motion of a chemical and physical order in the midst of the explosive substance which is decomposed, while it is purely physical in the midst of intermediary substances which suffer no decomposition; but that which distinguishes this sort of movement of the vibrations, properly so called, is, first of all, its extreme intensity, that is to say, the magnitude of the mechanical energy which it transmits; it is also the unique character of the explosive wave, which is propagated in contradistinction with the multiplicity of successive sonorous waves. Finally, it is essential to observe that the explosive material does not detonate because it transmits the movement, but on the contrary because it arrests it, and because it transforms on the spot the mechanical energy into thermal energy, capable of suddenly raising the temperature of the substance up to the degree which will produce its decomposition.

On page 670, Vol. VIII, we have referred to a new explosive called Panclastite, invented by Eugene Turpin. We are now in possession of a brochure* by the inventor, and from this we learn that the substance is made by mixing liquid nitrogen tetroxide (N_2O_4) with com-

*Notice sur la Panclastite découverte par Eugène Turpin. Paris, E. Bernard et Cie, 1882.

bustible substances such as the hydrocarbons; vegetable, animal and mineral oils; fats and their derivatives, but preferably with carbon disulphide. He proposes that the two substances should be kept apart until needed for use, when they may be mixed in the proportions considered best for the work in hand. The proportions which yield the most sensitive mixture are $2CS_2 + 3N_2O_4$, being about two volumes of the first to three volumes of the second. In making this mixture the temperature falls about 20°. When equilibrium is re-established the mixture burns with a most brilliant flame if ignited when freely exposed to the air. If confined in a vessel and ignited it burns until the pressure of the gases produces an explosion. Under these circumstances only a portion of the enclosed matter explodes and the remainder burns up quietly. If however it be exploded by a fulminate primer, whether confined or freely exposed, the explosion is complete and powerful; more powerful, it is claimed, than nitroglycerine or explosive gelatine. The reactions attending these different modes of decomposition vary. When the panclastite burns freely it leaves a deposit of sulphur, and sometimes of colorless crystals which yield nitrogen dioxide when brought in contact with water. When the panclastite is detonated carbon is deposited as a black residue. The author suggests that the reactions made be represented thus:

$$2CS_2 + 3N_2O_4 = 6N + 4SO_2 + 2CO_2,$$

or

$$2CS_2 + 3N_2O_4 = 6N + 4SO_3 + 2C.$$

The deposition of sulphur can only be explained by supposing a deficiency of nitrogen tetroxide. The formation of nitrogen dioxide or monoxide cannot be admitted, since carbon disulphide burns equally well with these two gases.

The advantages claimed for this explosive are greater power than dynamite, perfect safety of the separate constituents in transport and storage, insensitiveness of the mixture to blows, and easy control of the manufacture by the government, owing to the fact that nitrogen tetroxide is not met with in commerce.

The power is shown in the results of several experiments cited, where rocks and rails were broken and cylinders of lead compressed. Thus where 400 grams of dynamite No. 1 broke blocks of stone into 5 or 6 portions, 150 grams of panclastite broke them into 28 to 32 portions. In testing the sensitiveness a hammer weighing six kilograms—

	Exploded	gunpowder	in falling	0.50	meters.
	"	gun-cotton	"	0.25	"
	"	dynamite No. 1	"	0.15	"
	"	gum dynamite	"	0.20 to .25	"
	"	nitro-glycerine	"	0.10 to .15	"
had not	"	panclastite (liquid)	"	4.00	"

The sensitiveness can however be varied at will, and the material used in this experiment was the least sensitive of the mixtures.

In general panclastite is to be used in the liquid state, but if the solid state is preferred it may be absorbed by infusorial silica just as nitro-glycerine is.

M. Turpin proposes to utilize the light-giving power of panclastite, and has devised a lantern for burning the liquids which is very similar in construction to the oxyhydrogen lantern without the lime cylinder. He believes this may be used as a signal or search light in the field or for photographic purposes.

The heat developed by the combustion is also very great, being estimated at about 3000° C. Platinum fuses instantly under the action of this flame, and the mixture can fuse its own weight. Graphite also commences to fuse. Turpin has also devised a furnace by which this source of great heat may be utilized in the arts. All of these devices are represented in large phototypes.

Nitrogen tetroxide may be produced by heating lead nitrate,

$$2Pb(NO_3)_2 = 2PbO + 2N_2O_4 + O_2,$$

by acting on tin with nitric acid,

$$5Sn + 20HNO_3 = H_{10}Sn_5O_{15} + 5H_2O + 10N_2O_4,$$

by acting on nitryl chloride with silver nitrate,

$$NO_2Cl + AgNO_2 = AgCl + N_2O_4,$$

by union of oxygen with nitrogen trioxide,

$$2N_2O_3 + O_2 = 2N_2O_4.$$

When the nitrogen tetroxide gas formed by the above processes is passed into a freezing mixture of salt and ice it condenses in transparent crystals which melt at —9°, and which when once melted do not resolidify until cooled to —30°. Above —9° it forms a mobile liquid (sp. gr. 1.451) which boils at 22°. If water is present in the condenser the substance does not crystallize. Nitrogen tetroxide

probably undergoes dissociation at a comparatively low temperature. At 100° the gas consists chiefly of NO_2, at ordinary temperatures of N_2O_4, and at intermediate temperatures the gas is a varying mixture of these two. The liquid, at ordinary temperatures, gives off an abundance of reddish vapors, which, when mixed with air, are extremely difficult to condense. These vapors have a pungent, suffocating odor, an acid taste, are quite irrespirable, and stain the skin of a bright yellow. When mixed with water at a low temperature it is decomposed into nitric and nitrous acids; at an ordinary temperature, into nitric acid, water, and nitrogen dioxide. The results of the determination of its specific heat are given on page 443, Vol. VIII of these Proceedings. The heat of combination of the gas is —24.3, of the liquid —20.

The *Notes on Explosives* of W. N. Hill have been regarded as a most valuable and trustworthy guide to this study. The recent limited edition having been exhausted, we extract the following new notes, which correct, explain or extend the statements and descriptions of former editions.

The features of the nitro-glycerine process which are of the greatest importance are the strength of the acids and the complete washing of the products. The nitric acid should be of the greatest strength, since upon this depends the completeness of the conversion. With such acid, the maximum production of nitro-glycerine is attained and the oxidizing action is lessened. Also in such case the heat of the operation is much reduced, and the temperature of the reaction becomes of less importance. With the strongest acid the limits of temperature heretofore assigned may be considerably exceeded without injurious result. It has been stated that the mixing of the glycerine with the acid should be slowly performed. This should be understood to mean that the mixing is to be slowly performed, in order to preserve a low temperature during the operation; but, if the temperature is within the limit, the mixing should be performed as rapidly as possible, and the nitro-glycerine removed from the sphere of action. Rapidity of working is largely dependent upon the quality of acids employed, since the heat evolved is least when the strongest acid is used. In general with highly concentrated acid, not only is the proportional product increased, but also the reaction goes on more uniformly and is more easily controlled.

The manufacture of nitric acid for this purpose cannot be considered here, but it should be stated that acid for making nitro-glycerine is

now largely sold in the form of "mixed acid"—that is, the mixture of nitric acid and sulphuric acid ready for use. Much of this, however, does not come up to the standard which should be set up. The degree of strength of the nitric acid given before is too low. Acid of 1.49 to 1.51 specific gravity (48°–49° B.) should be taken, and this strength should be real and not factitious, as is often the case with acids nominally testing 50° and 52° Baume. To prepare such acid requires special care and precaution. The method of redistillation from oil of vitriol in glass retorts furnishes the finest acid, and in the writer's hand has worked extremely well, but it involves some trouble and expense.

The proportion of nitro-glycerine obtained is dependent almost entirely upon the acid used. If the glycerine is weak the product will fall off, but the small difference in strength of glycerine ordinarily found exercises little effect. But if the acids are weak the product is markedly less. This does not depend to any extent upon the method or form of apparatus operated, but only upon the acid taken. Weak acids will carry smaller quantities of glycerine and give lower proportional products than strong ones. Consequently, statements of relative products obtained are of comparatively little value unless accompanied by a statement of the kind of acid employed and the relative amount of glycerine treated. We have stated that in operating practically 1.6 to 1.75 parts of nitro-glycerine to one of glycerine were obtained, but that with the strongest nitric acid 1.96 to 2.03 parts were produced on a small scale. These figures are too low. It is not difficult to practically carry the proportion to rather more than two to one, using one part of glycerine to 7.5 or 8 parts of acid (mixed). With some care in the preparation of materials 2.2 parts can be obtained.

The method of making nitro-glycerine fully described in the body of this work is a convenient one from simplicity of apparatus, and has been found serviceable for the occasional requirements of the torpedo station. But for steady work on a large scale it is not as desirable as other methods of operating. The handling of small quantities of material takes much time and labor, and the reaction goes on more steadily and regularly with larger masses of material. The simplest, and a very effective method, is to use a large amount of the mixed acid (2000 to 3000 lbs.) in a large leaden or iron tub, containing also coils of pipe through which cold water is forced; this tub is set within another of wood, and the annular space between is traversed by

cold water; agitation of the acid is brought about by agitators driven by power (in some cases the agitators are driven by hand, but this is very objectionable). The glycerine is run in through an opening in the cover of the tub and distributed so as to fall upon the acid in a number of fine streams. The temperature is observed by a thermometer passing through the cover. When the desired amount of glycerine has been run in, the contents of the tub are drawn off into water and the nitro-glycerine separated.

In another form of apparatus a leaden tank is placed within a wooden one, so that water can be passed between them; in the tank revolves a hollow shaft, carrying paddles for a portion of its length, and for the remainder a cylinder, so that cold water may be led through the shaft and cylinder. The glycerine falls upon the surface of the revolving cylinder and is so conveyed into the acid, which is agitated by the paddles.

Different in principle is the process of Boutmy * and Faucher. In this the glycerine is mixed with half the sulphuric acid and the mixture allowed to cool. This is then added to the mixed acid (the nitric acid with the remainder of the sulphuric), the whole allowed to stand for twenty-four hours, and then thrown into water to separate the nitro-glycerine. Special advantages are claimed for the method, but it is doubtful if these claims are well founded. It is stated that it is more free from danger than others, and that it gives a large yield. With proper care the operation of conversion is not a dangerous one, and accidents at that stage are extremely rare by any method. The yield claimed is not in advance of that usually obtained, and, as already pointed out, the yield is governed by the quality of the acid used. This method is open to the grave objection that a large proportion of the nitro-glycerine is in contact with strong acid for a considerable time.

In Kurtz's method the vessel containing the acid is a narrow cylinder, with conical bottom of lead or iron, placed vertically. Two pipes extend to the bottom of this cylinder, one delivering glycerine and the other compressed air. The openings of these pipes are opposite to one another, so that the air-current strikes the glycerine and quickly diffuses it through the acid. The nitro-glycerine formed is supposed to rise to the surface of the liquid, and run off through a pipe to the washer. In another form of Kurtz's apparatus air is forced

* Nav. Inst. Proc. 5, 15.

into the glycerine, making a kind of emulsion, which is driven into the acid in the converting vessel by air pressure.

In all forms of apparatus for making nitro-glycerine the greatest care must be taken to prevent any accidental admixture of water with the charge in the converter. A very little water shows itself by the greater trouble and slowness experienced in running, and the product falls off. But if more water enters, the heat developed would be greater than can be carried away by the usual means of cooling and the charge is "fired." Usually this means only an active decomposition, accompanied by clouds of nitrous vapors. Slight "fires" may be stopped by vigorous agitation, but if the firing is persistent the contents of the tub should be run off as rapidly as possible. During drawing off, constant agitation of the liquid should be made to prevent separation of nitro-glycerine. Washing with water is the only mode spoken of. It is not difficult to wash nitro-glycerine thoroughly with water only, but the treatment must be continued until the washing is complete. This requires considerable time and labor. It is usual in manufacturing, therefore, to use an alkaline solution (sodium carbonate) to assist and expedite the washing process.

Hill has heretofore stated that frozen nitro-glycerine could not be fired. This is an error, it can be fired, but with much greater difficulty than when in the liquid state. In many later experiments he has often both failed and succeeded in exploding the frozen material, with the usual and larger amounts of fulminate.

Nitro-glycerine is but little used in the liquid state. In this country the principal use made of it in this condition is for "torpedoing" oil-wells. But for most purposes, such as mining, quarrying, engineering work, etc., the liquid is very rarely taken, while powders of which it is an essential ingredient are very largely employed. There are very few instances in which the intense and local action of liquid nitro-glycerine is demanded, but the field for the application of nitro-glycerine powders, which are more powerful and violent than ordinary blasting powder, is very extensive. These powders are of many kinds and many names. They may be considered in two ways:

1st. As nitro-glycerine preparations whose power and usefulness depend essentially upon the proportion of that substance which they contain; and 2d, according to the absorbent with which the nitro-glycerine is mixed. The nitro-glycerine is the valuable ingredient of all these powders. The principal object of their manufacture is to present nitro-glycerine in a safer, more manageable and more

useful form. They are made containing from 5 to 75 per cent. of nitro-glycerine. The lowest grades—5 to 10 per cent.—stand nearly on a level with ordinary blasting powder in regard to force and the purposes for which they are used. The powders ranging from 20 to 75 per cent. include most of the so-called high explosives now so largely manufactured in this and other countries. Those containing from 30 to 60 per cent. are the most extensively used. Serviceable powders must retain their nitro-glycerine at all practical temperatures, but must not be too dry, as they are then more difficult to handle.

In some powders the vehicle or solid matter with which the nitro-glycerine is mixed is entirely inert (for example, the silicious earth from which Nobel's dynamite is made), while in others the absorbents are substances themselves capable of decomposition or action either directly or under the powerful influence exercised by the nitro-glycerine explosion, so that they affect the resultant force exerted. From this we have the classification adopted by some writers, of preparations having an inactive base and those having an active base; but this classification is not satisfactory, since it is the nitro-glycerine which is the essential and important constituent, and since the bases or vehicles used are not definite substances or mixtures; therefore, although the absorbent materials might be such as could form an active base, yet from the proportions or manner of admixture employed they may practically exert no influence. The character of the absorbent may exercise influence upon the explosion of the powder in several ways. It may be composed of bodies which will react and add to the gas generated and so to the force exerted. Its physical condition may be such as to contain the nitro-glycerine in a state favorable to its best use. Also upon it depends the density of the finished powder, a matter of considerable practical importance.

Of the powders with inert absorbent, Nobel's or Kieselguhr dynamite is a good example. Another is the Magnesia Powder, or Hercules No. 1, in which carbonate of magnesia is the absorbent. Still another is the Cellulose Dynamite of Trauzl, in which purified wood pulp is the vehicle. These are rich powders—70 to 80 per cent. of nitro-glycerine—and are but little used commercially. They are well adapted for military purposes and are so applied.

There are very many kinds or varieties of the lower grades of nitro-glycerine powders, but essentially they are much alike in general composition. As the quantity of nitro-glycerine to be taken up is

moderate, great absorptive capacity is not required. Usually the absorbent is a mixture composed of nitrate of soda with one or more combustible substances, such as sawdust, wood pulp, charcoal, coal, rosin, etc., etc. If in such a preparation the nitrate and the combustible are properly proportioned and thoroughly mixed, they take part in the reaction and add force to the result. But in many cases these materials are in such bad proportions, or so imperfectly mixed, that little or no valuable action can take place between them. In this connection it is not necessary to enter into detailed descriptions of particular powders to be found in the market. Those of this class are less valuable for military use than the richer ones, but of course can be made to serve quite well for torpedoes, etc., in case of need.

Explosive gelatine or gelatine dynamite is made by dissolving photographic gun-cotton in nitro-glycerine, or by mixing nitro-glycerine with collodion, removing the solvent by evaporation. Nitro-glycerine, with the aid of heat, dissolves soluble gun-cotton, forming a gelatinous mass of firmness varying with the amount of gun-cotton contained. At 160°–170° F. solution of the gun-cotton and gelatinization quickly take place. In explosive gelatine the nitro-glycerine is very strongly retained, not being given up under heat or pressure. Explosive gelatine is very insensitive to blows and is not easily exploded, requiring a very powerful fuse, and is not injured by water. Various substances may be mixed with the materials used in preparing this agent to form mixtures of different kinds. Camphor dissolves freely in nitro-glycerine, so that camphorated explosive gelatine can easily be made containing it in any desired proportion. This preparation is even more insensitive to blows or other mechanical action than the simple gelatine. When struck by a rifle bullet fired at a distance of 80 feet it does not explode. To determine its explosion, either strong confinement or a peculiarly powerful fuse is required. In many respects explosive gelatine (particularly the camphorated variety) has special advantages for military purposes. It is considerably stronger than dynamite (75 per cent.) or compressed gun-cotton, and it is very free from liability to accident or injury in use or transportation. On the other hand its stability is a matter of question. Instances of its decomposition on keeping or after long exposure to moderate temperatures have been observed. It is probable that this difficulty may be removed. Soluble gun-cotton is apt to contain traces of free acid and to vary greatly in composition. Special care must be taken in making the gun-cotton to insure uniformity and

complete purification. If this tendency is overcome it is probable that explosive gelatine may be valuable for military purposes.

Some of the instances of decomposition of explosive gelatine have been cited in these Proceedings, Vol. VII, p. 486. In a prefatory note to Addendum I. of Gen. Abbot's report upon Submarine Mines, he states that "all the samples of the explosive gelatine remaining on hand after the trials detailed in the report have undergone spontaneous decomposition, separating into cellulose and free nitro-glycerine, with the copious evolution of nitrous fumes. This change occurred during the winter and spring of the current year (1881–1882), and was not caused by any exposure to high temperatures while in store."

A case of spontaneous decomposition of a small amount stored, freely exposed to air, in a dry room of even temperature, has occurred under my own observation. The camphorated explosive gelatine was wrapped in paraffine paper and then in light-brown wrapping paper. After something more than one year's exposure it was found in the early winter to be giving off nitrous fumes which had stained the wrapping paper, and to have shrunk considerably in volume, and that the outside of the paper was covered with congeries of fine crystals, while the odor of camphor was very strong. It was immediately put in a vessel of water, and after a short time the mass, which was friable, disintegrated. The camphor odor soon disappeared and the water became of a straw color, gave a strong acid reaction, and showed a slight trace of nitrous acid, but no nitric acid. On evaporation of the filtered liquid, oxalic acid crystallized out in quantity, and on evaporation of the mother liquid farther, on the water bath, a sugar-like mass was obtained which gave the glucose reaction with Fehling's solution.

The paraffine was regained unchanged and the paper was recovered, but in a flocculent condition, and with the color bleached from the brown. Careful search failed to reveal the presence of glycerine, nitro-glycerine or gun-cotton. The cellulose from the gun-cotton could not well be detected (if it existed) in the presence of so much flocculent cellulose from the paper.

The results obtained by De Luca in his "Researches on the Spontaneous Decomposition of Gun-Cotton," *Comptes Rendus*, **59**, 487, September 12, 1847, are interesting in this connection. Gun-

cotton decomposes most rapidly when heated to 50° on a water bath, next by sunlight, more slowly by diffused light, and very slowly in darkness. The gun-cotton first shrinks to $\frac{1}{10}$ of its original volume, next it begins to become gum-like and sticky, then it swells; during all these phases it gives off nitrous fumes, but especially during the last. For the fourth phase the gas ceases to be evolved, and the mass becomes brittle and of a light color like sugar. The products are nitrous compounds with formic and acetic acids in the state of a gas, and an amorphous, porous, sugar-like body, almost entirely soluble in water and containing an abundance of glucose, gummy matter, oxalic acid, a small quantity of formic acid, and a new acid, of which he obtained the lead and silver salts for later examination. From 100 grams of gun-cotton he obtained about 14 grams of glucose.

As regards the decomposition of nitro-glycerine, A. Brull states, on page 26 of his "Études sur la Nitro-glycérine" (Paris, 1875), that concentrated sulphuric acid, cencentrated nitric acid and concentrated soda solution attack nitro-glycerine even in the cold and provoke a progressive decomposition. Nitro-glycerine, which retains a trace of free acid, is not stable. In general, the decomposition is extremely slow and tranquil. It disengages at first nitrous vapors, the liquid taking a greenish color. Then there is formed nitrogen and carbon dioxides and crystals of oxalic acid, and after some months the entire mass is transformed into a greenish, gelatinous matter composed of oxalic acid, water and ammonia. Sometimes, if the temperature is high, as when heated by the sun, the decomposition is more active, but it very rarely causes an explosion.

Major W. McClintock, R. A., has been making a series of experiments with small shot in order to test the accuracy of various statements as to the strength of Schultze powder (sawdust powder) and E. C. powder (granulated gun-cotton), and also to determine the velocity when black gunpowder was used, since little was known concerning this. The Boulengé chronograph was used for measuring the observed velocities and Bashforth's tables were employed for calculating the remainder. All the cartridges used were bought from the same tradesmen, who obtained them direct from the factory, and although the method of loading was identical in all, and the powder (in those charged with gunpowder) was supposed not to vary in quality, it was found that no two boxes gave similar results. The cartridges were then examined, and it was almost invariably found that

the amount of powder was deficient and the weight of shot in excess. This deficiency of powder amounted in one case to 8 grains, and the excess of shot in the same cartridge to 64 grains. The powder too was found to vary in appearance and size of grain, and when some cartridges from each box were stripped and carefully reloaded with correctly weighed charges, the muzzle velocities showed that the powder varied very much in strength. These experiments show that the mean velocity obtained with *unweighed* charges should not be considered as proof of the quality of the cartridges, because one or two rounds which have a heavy powder, or light shot charge, may unduly raise the average. Taking weighed charges of 492 grains (= 1⅛ oz.) of shot, 82 grains (= 3 drams) of gunpowder, and from 45 to 47 grains of Schultze or E. C. powder, it was found that the average velocity of the last two was over 100 f. s. greater than gunpowder. The determined velocities of even the carefully made-up charges showed considerable variations, but source of error exists in the use of small shot, owing to the fact that the quickest pellets of the charge need not always cut the wires but may pass through the meshes. Major McClintock thinks that his experiments with the Schultze and E. C. powders were so few that it would be premature to form any decided opinions concerning them at present, but he states that these explosives possess great strength (sometimes too great), make little smoke and cause slight fouling, but the velocities they give are not regular. These experiments are given very much in detail, with copious tables, and are accompanied by an account of researches made to determine how the boring of the gun-barrels affects the muzzle velocity.—(*Proc. Roy. Artil. Inst.* **12**, 332, Aug. 1883.)

In these notes, Vol. VIII, p. 444, an abstract of the testimony in the case of the Atlantic Giant Powder Co. against the Dittmar Co. is given. Recently some of the papers in the suits of the same company against George A. Goodyear, George W. Townsend, Michael Brady, and the Neptune Powder Co. have come into our hands. The compositions of the various explosives which the Atlantic Giant Powder Co. regarded as infringements of their patents were as follows:

Vulcan Powder.

Nitro-glycerine	32.60 per cent.
Nitrate of soda	49.46
Charcoal	9.63
Sulphur	8.31

Neptune Powder.

Nitro-glycerine	32.66 per cent.
Nitrate of soda	45.04
Charcoal	17.44
Sulphur	4.86
Ash	0.94

Miners' Powder Company Dynamite.

Nitro-glycerine	32.91 per cent.
Nitrate of soda	49.88
Charcoal, wood and partially charred wood	17.21
Ash	1.18

Brady's Dynamite or Vulcan Powder.

Nitro-glycerine	33.00 per cent.
Nitrate of soda	50.00
Charcoal	10.00
Sulphur	7.00

It will be observed that all these powders are practically dynamites in which gunpowder is used in place of infusorial earth as the absorbent. In regard to the powder made by Michael Brady, Thomas Varney, a manufacturer of nitro-glycerine, dynamite, &c., testifies that it "belongs to a class which is now quite large and known as high explosive powder. Some of their names are Giant Powder, Mica Powder, Vulcan Powder, Jupiter Powder, Neptune Powder, Thunderbolt Powder, Hercules Powder, Titan Powder, Rend-Rock Powder, Vigorite Powder, Lithofracteur Dualin.

"They are made by mixing nitro-glycerine with a dry pulverized substance, or mixture of substances such as have the capacity of taking up and holding a sufficient proportion of nitro-glycerine by absorption to make the mixture an effective explosive, and yet without being in such excess as to separate from the mass by leakage or compression, and at the same time the absorbent solids employed being such as will not chemically injure the proper explosive quality of the nitro-glycerine, and such as will render the mass practically inexplodible by concussions which ordinarily occur in handling and transportation. The solid ingredients, to-wit, the nitrate of soda, charcoal and sulphur, are first ground or otherwise pulverized, and dried if necessary. The nitro-glycerine is then carefully mixed with

them, so as to make a mass as nearly homogeneous as practicable, and the powder is then packed for market.

"In the manufacture of Vulcan powder there is a combination of nitro-glycerine with absorbent substances which are the equivalents of infusorial earth; and this combination constitutes an explosive compound, which has all the properties and qualities of the compound made by combining nitro-glycerine with infusorial earth in making dynamite or Giant powder, or with mica scales in making Mica powder, or with mealed gunpowder in making Vulcan powder.

"In the first place, each of the materials used as absorbents in the Vulcan powder is solid. In the next place they are all free from any quality which will decompose, destroy or injure the nitro-glycerine. They are capable of pulverization. They are also dry, or may be made so. When pulverized each of them alone, or all of them in the proportions actually used, or in any other proportions, they will absorb and hold nitro-glycerine to the extent required by the patent sued upon, to-wit, enough to make an explosive powder without rendering the powder leaky, and without any explosive aid from the absorbents themselves.

"Dry pulverized nitrate of soda will thus hold 30 per cent. of nitro-glycerine, charcoal 45 per cent., sulphur 30 per cent. (all these are explosive compounds), and when combined, as in Vulcan powder, they will thus hold 33 per cent."

After asserting that the absorbent of the Vulcan powder is similar to the infusorial earth in converting the liquid nitro-glycerine into the solid form, he adds: "The Vulcan powder absorbent, like that of the Neptune and Vigorite absorbents, has one quality not possessed by infusorial earth, to-wit, combustibility; but this quality does not affect the powder as dynamite. Its only effect is to allow the absorbent to be burned by the heat of the exploding nitro-glycerine, thus adding gas and force to the explosion. Vulcan powder is no more combustible than dynamite of infusorial earth; in fact, not as much so—that is, if an equal quantity of the two be set on fire, the Vulcan powder will burn the longest. Vulcan powder is practically as safe against concussion as infusorial earth dynamite.

"This particular class of powders, with combustible absorbents, has been made and sold by the complainant since the commencement of its business, which was in October, 1871. It had previously been made and sold by Alfred Nobel & Co. and by the Giant Powder Company, and by no other person or party prior to its use by them,

to the best of my knowledge and belief. It has always been made and sold by the two Giant Powder companies, under the name Giant Powder No. 2, and labelled as patented under the original dynamite patent of May 26, 1868, and its reissues. Nobel & Co. have always made and sold it as Dynamite No. 2. The two Giant Powder companies have made and sold more of No. 2 than of No. 1—meaning by No. 1 infusorial earth dynamite, or Giant powder. The nitrates of our No. 2 have always been those of potash or soda. It has been the same with Vulcan powder. Our carbons have been rosin, bituminous coal, pulverized wood or sawdust. These have been our favorite materials, but we have experimented with and tried in practice for a longer or shorter time many other things. As to charcoal, one of the earliest things tried, we found it not so good as several other things. As to sulphur, we long ago abandoned its use. In gunpowder to be burned by itself it is useful as facilitating ignition; but when combined with nitro-glycerine it is not needed for this purpose, as the absorbent is readily fired by the exploding nitro-glycerine. For absorbing it is no better than the nitrate, and not as good as charcoal, or any of the carbons or hydrocarbons used in absorbents. In other words, the sulphur in Vulcan powder is useless for any purpose except as an absorbent, and for that purpose would be better replaced by the same amount of nitrate and carbonaceous matter.

"The fine pulverization of the Vulcan absorbent is mainly for the purpose of increasing its absorbent capacity. Ordinary well-grained gunpowder will not safely take and hold over ten per cent. of nitro-glycerine; but in the form of meal powder, its state before being grained, it will take and safely hold 45 to 50 per cent. The pulverization may be considered as having another advantage for purposes of absorbents, to-wit, the nitro-glycerine will be more intimately distributed in fine than in coarse materials, and the heat of the exploding oil will take effect quicker, and thus add force to the explosion.

"When Vulcan powder is exploded in practical use an exploder is always used. This exploder, by the force of its explosion, explodes the nitro-glycerine contained in the powder precisely as the nitro-glycerine is exploded in No. 1 Dynamite. The explosion of the nitro-glycerine in No. 1 does not affect the infusorial earth, which is incombustible, but in No. 2 Neptune, Vigorite, Vulcan, &c., the nitro-glycerine explosion produces high heat, which burns up the combustible absorbent. Any pulverized combustible would be consumed in like manner. Sawdust, charcoal, dried paper pulp, rosin, paraffine,

pitch and other carbons or hydrocarbons which have been used in making No. 2 are all completely consumed, just as is the Vulcan absorbent."

Robert J. Howe, a dealer in powder and various explosives, and formerly foreman of the Laflin Powder Company's mills, testified for the defendants in the Neptune Powder Company case as follows:

"Neptune powder compound, before adding nitro-glycerine, is in the form of powder dust, and is an explosive in itself. If ten per cent., or any greater proportion of nitro-glycerine which it can retain, is added to it, the resulting compound is explosive, while infusorial earth must contain over thirty per cent. of nitro-glycerine to explode at all, and a much larger proportion to make an effective explosive. Grained gunpowder, mealed gunpowder, gunpowder dust or Neptune compound will not take up and retain more than about thirty per cent. Difference in temperature makes a difference in the retentive power of the substances. They will retain more in cold weather than in warm. My experience teaches me that about thirty per cent. of nitro-glycerine is the quantity they can be relied upon in practice to retain. Dry pulverized nitrate of soda will not take up and retain thirty per cent. of nitro-glycerine, but only about fifteen per cent. It might be made to retain, under certain conditions of temperature, twenty per cent., but when thirty per cent. is added to it it slowly trickles from it, and upon being squeezed in the hand it is discharged between the fingers.

"A mixture of 70 parts of either infusorial earth, charcoal or sawdust with 30 parts of nitro-glycerine is inexplosive, yet either of the following mixtures are explosive—

Nitrate of soda	75	or	40	parts.
Charcoal	10			"
Nitro-glycerine	15		15	"
Sawdust			20	"

Also these are explosive—

Gunpowder dust	90		parts.
Neptune compound		90	"
Nitro-glycerine	10	10	"

"The nitro-glycerine does receive explosive aid from the Neptune compound, from gunpowder, from gunpowder dust and from a mixture of sawdust and nitrate of soda. It is a well-known fact that

gunpowder is more effective when exploded by percussion caps than by simple fuse. Some consumers (contractors) always use percussion caps for that purpose. For the same reason, caps are better to explode Neptune powder, but Neptune powder is largely used by some parties and exploded (without cap) by fuse alone. In such use the powder of the Neptune powder explodes the nitro-glycerine of the Neptune powder in the same manner as indicated in the patent to Nobel, No. 50,617, filed 10th May, 1865."

Dr. Henry Morton, President of the Stevens Institute, testified "That while at North Adams, in December, 1875, I mixed 52 parts of nitro-glycerine with 48 parts of infusorial earth sent me by the complainants, and made this into a cartridge of the usual form, and inserted in this an 'exploder' or cap containing 16 grains of fulminating mercury. When this was fired in the usual way the cartridge did not explode. I then placed another 'exploder' or cap containing 22 grains of the fulminate in the cartridge, and enclosed the whole in a short wrought-iron tube, tamping the ends with sand. On firing this 'exploder' the iron tube was split open by the force of its explosion, but the mixture of infusorial earth and nitro-glycerine remained unaffected as before. I am, therefore, quite certain that a mixture of infusorial earth and nitro-glycerine in the proportions found by Dr. Hayes between the gunpowder and nitro-glycerine in the explosive compound* of defendants, would be totally inexplodible."

Prof. Morton then goes on to show that using various devices for increasing the explosive force of gunpowder is no new thing and cites the following: "In the *Chemical News*, London, July 6, 1866, on p. 16, he finds as follows: Some experiments were in the first instance made with gunpowder the grains of which had been saturated with nitro-glycerine. This powder burned much as usual, but with a brighter flame in open air. When confined in shells or blast holes, greater effects were, however, produced with it than with ordinary gunpowder; its destructive action is described as having been from three to six times greater than that of powder.

"The same account is published in the *Proceedings of the Royal Institution*, Vol. IV, p. 621, London, 1866. It is also published in the Journal of the Franklin Institute, Philadelphia, 1866, Vol. 52, p. 275.

"This deponent further says, that the increasing of the explosive force of gunpowder by the admixture of various bodies with it has

* Neptune powder.

been from time to time practiced from the early part of this century; thus, in the *Encyclopædia Britannica*, Edinburgh, 1815, is found an account of experiments made by Count Rumford. He used oil of turpentine, quicksilver, salt of tartar, sal ammoniac and brass filings, with this object. In *Cutbush's Pyrotechny*, Philadelphia, 1825, p. 140, we find: Quicklime is said to increase the force of powder. Dr. Baine says that three ounces of pulverized quicklime being added to one pound of gunpowder, its force will be augmented one-third. M. Vergnaud, in a work on fulminating powders in 1846, asserts that certain rifle powder consisted of gunpowder mixed with fulminate of mercury. In the *Mechanics Magazine*, London, 1825, Vol. 3, p. 275, we find a description of experiments with powder mixed with oil, which showed an increase of effect. In *Ure's Dictionary*, New York, 1853, p. 174, we find admixture of sawdust with gunpowder recommended as increasing its explosive force. In the *London Artizan* of 1862 we have a description of Mr. Bennet's improved blasting powder, which consisted of a mixture in which lime was added to the usual ingredient of gunpowder. In the *American Repertory*, New York, 1841, Mr. Mayer proposes admixture of rosin with gunpowder to increase its effect in blasting."

The injunctions against the manufacturers of Neptune and Vulcan powders were granted. The value of this monopoly may be shown as follows: It is claimed that with proper exploders a dynamite composed of 30 per cent. nitro-glycerine and 70 per cent. meal powder will do as much work as a dynamite composed of 75 per cent. of nitro-glycerine and 25 per cent. of infusorial silica. The difference in cost may be estimated as follows:

Vulcan Powder.

70 lbs. of meal powder, @ .04	$ 2.80
30 " nitro-glycerine, @ .40	12.00
100 lbs. of powder cost	$14.80

Dynamite No. 1.

25 lbs. of infusorial silica, @ .03	.75
75 " nitro-glycerine, @ .40	30.00
100 lbs. of dynamite cost	$30.75

In a previous suit Judge Blatchford issued an injunction against the manufacture of the following powders:

	No. 1.	No. 2.
Nitro-glycerine	67.64	27.86
Cellulose (paper stock)	16.82 (sawdust and charcoal)	5.59
Nitrate of soda	15.54	66.55

The Popular Science News, James R. Nichols, M. D., editor, 17, 53, May 1883, contains an editorial article entitled, "What is Dynamite?" from which we extract the following as being a good example of popular science. Referring to the recent difficulties in England, Russia, Spain and elsewhere in Europe, it says: "In dynamite we have a pasty black mass, almost perfectly safe to handle, of which enough can be carried in a side pocket to destroy the lives of a hundred men, if favorably situated, or shatter a building nearly as effectively as could be done with half a barrel of gunpowder placed under it.

"What is dynamite? How is it manufactured? We are fully prepared to answer these questions, as we manufactured the first nitro-glycerine ever made in the United States, nearly twenty years ago, and have had some experiences with it not pleasant to recall. Dynamite is simply nitro-glycerine mixed with an adulterant to render it safe to transport. The added ingredient is usually a fine earth of great absorbent capacity. It has been found that the best kind is the earth which good housewives use to polish their silver with, properly called *infusorial* earth, because it is made up of the fossil remains of minute organisms. Dynamite, then, is a mixture of innocent polishing powder and sweet, bland glycerine, after it has been acted upon by nitric acid. There is nothing apparently very frightful in this mixture. We can eat glycerine on our puddings and griddle-cakes and grow fat upon it; and a box of silver polish in the house is as harmless as a cake of soap.

"In what has been stated, a strange law of chemical combination comes into view, a law by which a vast change is produced in innocent bodies by a slight disturbance of their molecular constitution. We disturb the molecular constitution of glycerine by subjecting it to the action of nitric acid, by which nitrogen becomes a constituent of the body, and its whole chemical nature and relationship are changed.

"The dull, stupid nitrogen which exists so abundantly in the air, and which we breathe into our lungs every moment, day and night, becomes the agent which confers upon glycerine the most terrific powers possessed by any agent, save two, known to man. Does not this fact teach an impressive lesson as to the mystery of the forces of nature, and of man's capability of bringing them into action, and we may say, into subjection? If such facts do not cause a feeling of respect for chemical science, it is difficult to conceive of any that will.

"In the manufacture of nitro-glycerine we simply mix with pure glycerine a certain proportion of sulphuric and nitric acids and stir the mixture until the reactions occur, which is in about twenty minutes. The vessels must be placed in freezing mixtures, for if at any time the temperature rises above 32° F. decomposition occurs, and if there is no explosion the whole mass goes off in a vast cloud of nitrous acid vapors which are troublesome and dangerous.

"We never ventured to act upon more than one hundred grains of glycerine at a time, and with this small amount the danger was great and accidents were not a few.

"Our method was to arrange upon a shelf, in a refrigerating mixture, twelve beaker glasses, each containing one hundred grains of glycerine, and into each of them the mixed acids were slowly allowed to enter, the thermometer being anxiously watched all the time. If the heat from the reactions rose above 32° in any glass, away would go the contents, filling the laboratory so densely with red fumes that no object could be seen six feet distant.

"It was regarded as a successful experiment if we saved four glasses out of the dozen. Whilst at present the methods of production are not different, the apparatus and appliances are greatly improved. It must be remembered that we were pioneers in the dangerous manufacture, and but little of the product was needed in medicine and the arts. Now the consumption is enormous, and large manufactories are established in many sections of the country. The United States government chemists make the best nitro-glycerine at the laboratory at Newport, Rhode Island. It is used largely for filling torpedoes.

"In what has been said we have endeavored to afford a popular view of the chemistry of dynamite. It does not explode at the touch of fire, as does gunpowder, but it must have brought to bear upon it, or in contact with it, another explosive agent, a *fulminate*. A fulminate of mercury is better than a fulminate of silver, for the *rhythm* of

its detonation is more in accord with that of dynamite. Dynamite *detonates*, and does not explode as does gunpowder. Its action is so much quicker than the movement of air that it strikes against a column of air with the same force as a hammer falling upon a blacksmith's anvil."

The following books may be of interest to students of explosives :

Die Grundsätze der Thermochemie. Dr. Hans Jahn. Vienna, 1882. Alfred Holder, 8vo, 238 pp.

Thermochemische Untersuchungen. Julius Thomsen. Vol. I. Neutralization und verwandte Phenomena, 449 pp. Vol. II. Metalloide, 506 pp. Leipzig, 1882. J. A. Barth.

Lehr- und Handbuch der Thermochemie. Dr. Alex. Naumann. Brunswick, 1882, F. Vieweg und Sohn. 606 pp.

The Explosive Art, 1875, and the Orders in Council of April 20, 1883, their Prejudicial Effect on Mining and Quarrying, and the Encouragement they give to Fenians. London, 1883, A. P. Blundell & Co.

NAVAL INSTITUTE, ANNAPOLIS, MD.

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SUGGESTIONS IN FAVOR OF MORE PRACTICAL AND EFFICIENT SERVICE EXERCISES.

By Lieutenant Nathan Sargent, U. S. N.

The signs of the times, as shown by the recommendations of the President's Message, the Report of the Secretary of the Navy, the leading articles of prominent newspapers, and the late resolutions of the Union League Club of New York and Chamber of Commerce of San Francisco, go to prove that the consensus of opinion throughout the country is in favor of a decided increase of the matériel of the Navy, and that we may soon expect to have the service supplied with a fleet of modern and effective vessels.

These vessels, if not formidable, will at least be excellent ones of their type; and being armed with guns of the most approved pattern and highest power, will not be handicapped by either the antiquated smoothbore, or the makeshift converted rifle, to which we have so long been accustomed.

This, of course, is a matter of great congratulation to the naval officer; who, in hailing the dawn of a new era, cannot help remembering how for many years he has been mortified by being obliged to cruise in foreign waters, in vessels of a type some twenty years behind the age, and whose ingenuity has often been put to the test in attempting to answer the questions propounded by foreigners and foreign officials, who could not understand the anomaly of the richest country in the world having the weakest navy, with types of ships and guns long since abandoned by the principal maritime powers.

But, however satisfactory may be our new ships, and however powerful our new guns, their effectiveness will be almost *nil*, unless we have an efficient, well trained, and intelligent personnel to man them. For this, the responsibility rests directly with the officers of the service.

For many years past, whenever the lamentable state of our navy has been mentioned, a strong contrast has at once been drawn between ships and personnel, and the latter has always been declared equal to that of any other service. So it may be, so far as raw material is concerned; but, if untrained, and unacquainted with the resources, requirements, and methods of modern naval warfare, it will be substantially useless in any conflict, even if opposed to an enemy far inferior in natural qualifications.

Our service has a glorious record in the past, but its record is due largely to the fact that the careful training its men had received rendered them much superior to those with whom they came in conflict. In the French war and in the war of 1812 our successes were owing, not only to the superiority of our ships (as urged by the enemy), but also to the fact that our adversaries paid little attention to gunnery in exercising their crews; our men, on the contrary, had been instructed with the utmost care, and particular consideration had been given to their target practice and manner of firing in a seaway. The good results of this training were shown by the favorable issue of many actions, in which we had to contend, not only with equal force and valor, but with the prestige established by years of maritime supremacy. The most noted of our reverses in the war of 1812 was when the unfortunate Chesapeake, with an untrained crew, was opposed to a vessel commanded by an officer who, in a commission of over four years, had been untiring in his endeavors to improve the gunnery of his men.

With such an experience to look back upon, one might imagine that the present day would find our personnel at the highest point of excellence, with a training far in advance of that of foreign navies, and ready for any emergency of sudden war. That such is not the case is due to the fact that a prevailing characteristic of our service is extreme conservatism. Any proposed change from the existing order of things, in whatever manner, or however sensible and beneficial, raises a storm of objection and disapproval; the more requisite the change, and the more apparent to thinking minds its necessity, the more decided seem its opponents, and the more strenuous their efforts to prevent its accomplishment. This tendency blocks the way to any improvement in the training of our crews, and explains why there has been little or no alteration in the usual drills and exercises for the last twenty years.

But, the ultimate object of a naval force being *readiness for* WAR,

we cannot afford to stand still while other nations are advancing, and it behooves us, the officers of the Navy, to see that its personnel is kept up to the mark of modern effectiveness, and is made worthy of its traditions and reputation.

How far behind the times we are may be seen by an inspection of any of our fleet or ship routines, showing what drills and exercises are considered necessary. Sail and spar drill, general and fire quarters, and an occasional boat exercise, constitute the major part of all requirements; while at rare intervals a landing party is organized, and the men are sent on shore in their mustering clothes to go through a dress-parade, which, as a military ceremonial is generally a failure, and as a land evolution is of no utility whatever as a preparation for service.

Some three years ago the writer witnessed the landing of a large naval force at Fortress Monroe. For weeks the papers had been heralding a grand naval review, and the New York dailies and illustrated journals had sent their correspondents and artists to describe and depict the interesting manœuvres that were anticipated. The North Atlantic and Training Squadrons had rendezvoused in Hampton Roads, the Secretary of the Navy and other high officials were present, and there was nothing to prevent a series of exercises of great utility and interest. But what was the result? There were some fleet and ship drills with sails and great guns, but little attention was paid to them, the main object of interest being the proposed landing party of blue-jackets and marines. At last a signal was made for the force to embark, and soon after, for the squadrons of boats to form opposite the beach. There was no attempt to simulate the covering of the party by a fire from either launches or vessels, during the full hour consumed in forming the boats into line; and the presence of the most insignificant number of an enemy on the dunes of the beach would have been sufficient to effectually prevent all chances of landing. The same lack of any resemblance to real service was shown in the landing itself. There was a general race and scramble for the beach, the men jumped out, pulled up their boats, and formed into battalions; no effort being made to throw out skirmishers, nor to guard against surprise by any of the precautions that would necessarily be taken in time of war. The shore organization effected, the party was marched into the fort, and were drilled at forming and changing front *in mass*, and in having a brigade dress-parade and review.

Now, of what use to any one, officer or man, was such an exercise as this, and what experience could be gained from it, other than the negative one of teaching us to avoid all of its defective details?

All recent naval expeditions and operations have shown the necessity of having an effective landing force, well organized and capable of rendering good service on shore, by being properly equipped and instructed in some system of tactics adapted to the duties likely to be required of it.

Every one will acknowledge that an exercise of this description should be one calculated to make both officers and men fully conversant with the dangers and difficulties likely to be encountered in actual service. The autumn manœuvres of the German and French armies do not consist of reviews and dress-parades, but of operations extending over several days, and embracing all the discomforts and hardships, and calling for all the skill in tactics and strategy, necessary to actual campaigning. Again, men are no longer fought in masses; the best military authorities recognize and announce the fact that open order is the formation of the future, yet the skirmish drill is usually the last thing taught the sailor. If, perchance, a progressive divisional officer desires to drill his men as skirmishers, he is likely to have the greatest difficulty in obtaining the requisite permission from the conservative first lieutenant, and is perhaps looked on by others as a *rara avis*, holding unusual or ridiculous ideas, or as one who is anxious to pose in the role of a reformer. But the purpose of our drills is not only to give the sailor employment and exercise, but especially to fit him for such service as he may at any time be called upon to perform, whether on board ship, in torpedo boats, or on shore.

The object of each system of instruction should be to impart the knowledge that will earliest bring the seaman to the desired state of proficiency. What has recently been said by Lord Wolseley in reference to the English soldier may apply with equal force to the sailor. He remarks: "As nowadays you have only a limited time to teach him in, you ought to devote it exclusively to instruction in useful things; and in teaching him useful things you will discipline his mind and body quite as well as if you taught him complicated manœuvres, which are very pretty to look at, but utterly impracticable in the field."

The aim of modern instruction is *utility*, and the best and most expeditious way of acquiring that utility is what is needed afloat as well

as on shore. The man-of-war's-man of to-day is a very different being from the sailor of fifty years ago, and is a person from whom a much greater degree of intelligence is expected and required; more attention should therefore be given to his instruction as necessitated by the great changes and improvements in great guns, machine guns, magazine guns, small arms, and torpedoes. The probability of having to use or to contend with any or all of these new inventions should necessarily be considered, and our drills should be more in conformity with such requirements. Should this change take place we might soon miss the mediæval cry of "boarders away!" and the sight of the picked men of the ship rushing to the most exposed parts of the upper deck, and with a mighty cheer swarming up on the bulwarks and cleaving the air with their cutlasses. How many minutes, nay, seconds, would it require an enemy, with the modern complement of Hotchkiss, Nordenfeldt, Gardner, or Gatling guns, to sweep them away as so much chaff? Boarders may still be needed in cases of ramming, but they must be manœuvred very differently from the manner of the past.

The daily drills might, with propriety, be carried on in a manner more consistent with the increased intelligence of our men, and the divisional officer should act more in the capacity of an instructor, and less in that of a simple drill-master. Great attention should be paid to target practice with great guns, machine guns and small arms;* the battery should be frequently laid for concentrated firing, both by hand and by electrical action; movable targets should be improvised, and the vessel should be under way when firing at them; the effect of drift and of wind blowing across the line of fire should be explained, not only to the gun captains, but also to others who may be called upon to take their place; the manipulation of fuses should be familiar to all; the use of machine guns on deck and aloft, and the defence of tops against small-arm fire, are part of the requirements of the future; while readiness for ramming and for launching torpedoes in action are preparations for emergencies likely to occur with even the weakest wooden vessel.

The subject of torpedoes has become a very important one, and likely to be of momentous interest in the naval warfare of the future. The truism of this statement being universally acknowledged, one might imagine that we should find both officers and men fully in-

* The English have an effective movable small-arm target, representing a man running from cover to cover.

structed in every detail of the subject, and that frequent drills with and against torpedoes would be held. Unfortunately, even in this important particular we do not seem disposed to keep up with the times. To be sure, there is a class of officers every summer at the Torpedo School for a short course of three months; but the knowledge obtained in that time is necessarily superficial, and so rarely brought into requisition on board ship that the greater part of it is soon forgotten.

As for the men, they receive no instruction whatever, and the only chance they ever have of acquiring any information on the subject is when, very rarely, a launch is sent out to explode a spar torpedo, usually as a test of the electrical machine, and not as a movement against an imaginary enemy.* While other nations (as the English in their fleet exercises last July, in Bantry Bay, and the Italians, in their manœuvres last November) are accustoming their men to the different kinds of torpedoes, mines and countermines, and to the manipulation of them; to torpedo attack and defence, by day and by night, at anchor and under way; to the obstructing and clearing of harbors and channel ways; to the use of the electric search light, torpedo nettings, machine guns and other means of resisting attacks from swift torpedo boats, we are standing idle, and are doing little or nothing to render our seamen conversant with such emergencies, or to impart to them the requisite knowledge for prompt and proper action in case of such necessity. At the present time, the smallest and most insignificant navies are being supplied with English torpedo boats, of the most approved models and greatest speed; yet we, with our ostrich policy, do not even attempt to anticipate the manner of defending ourselves, in case we should suddenly be drawn into war with any of them. If the effectiveness of the service be not a sufficient consideration, we

*The British lords of the admiralty, considering it desirable that instruction in the torpedo school should form an essential portion of the course for all seamen gunners, have made the following arrangements which are to take effect from November 16: "Every seaman gunner on requalifying, and every seaman in future desirous of qualifying, in a gunnery school, will also be required to go through a course of torpedo instruction in a torpedo school before being available for draft for service afloat. The gunnery course for qualifying and requalifying in the gunnery ship is to remain as at present. The time under torpedo instruction, including examination, will be sixty working days."

The writer has known of but one ship in our service where the men received any special torpedo instruction, and in that case the officers of the vessel were severely criticized for "teaching their men too much."

might be guided by a certain old and well-established aphorism, and on the score of self-preservation take the needed measures of preparation.

A night attack from twenty-knot torpedo boats, with all the moral effect of uncertainty and dread, even with the most approved means of defence, will be the greatest strain upon their nerve and discipline that a ship's company may have to encounter; but a proper knowledge of what has been done under similar circumstances, and of the good result of quick and concerted action, will go far towards preventing the panic to be feared at such a moment, and will result in the adoption of decisive and effective measures. An occasional exercise at preparation for such an attack would not only render our officers and men conversant with all the circumstances of the case, but many points which otherwise would not have been foreseen might be suggested by the actual occurrences, if part of the crew should represent an attacking force. Exercises of this kind would give to every one a certain amount of knowledge and experience, which at some future moment might be of great benefit either in attacking an enemy or in acting in our own defence.

With other considerations of practicable and practical readiness for war, opportunities should be given officers to perfect themselves in the management of the vessel to which they are attached, by experiments calculated to give them a just idea of her evolutive qualities; of the effect of different positions of the helm, both in going ahead and astern, and of the difference caused by the trim of the ship or by her heeling; of her turning powers at different speed, her tactical diameter, etc., etc. The effect of concentrated and other firing under all circumstances of heel, etc., and in all weathers should be carefully noted for future reference. More frequent fleet sailing and the use of naval tactics, both with steam launches and with the vessels of the squadron, should be carried on, not only for instruction in the tactics, but also as a means of acquainting officers with the steering and other qualities of their ships. The mere retaining of position on a dark night calls for an extreme degree of care and watchfulness, and is in itself a valuable experience; as an English authority has recently remarked,* " It can only be understood by those who have seen the confusion caused by two or three vessels losing their position, or by those who know the watchfulness and the precautions called for by a manœuvre necessitating a great change of course."

* Captain R. H. Harris, in Journal United Service Institution.

The attention of officers could also with propriety be given to a consideration of a tactical line of policy, in case of possible war with the country in whose waters they happen to be serving, and to the strategical advantages of certain points within their limits. A habit of such observation and thought might stand them in good stead in the future, and be of great advantage not only to the service, but also to themselves.

These few suggestions are offered with all due diffidence, not so much with any confidence in their own utility, as in the hope that their discussion may call forth others of real value. The conservative element already mentioned would oppose a change of any kind, but most of us will acknowledge that we cannot go on in the methods of twenty years ago, and will agree that with our new ships we should have a personnel equal in all respects to those of other nations. Our men are inferior to none in intelligence, but their intelligence will be of no avail without the proper instruction and exercises in accordance with modern inventions and practices.

All that the writer advocates is that our drills shall conform to the requirements of modern warfare, and he feels assured that every one will agree with him as to the propriety (although they may not be of the same mind as to the manner) of maintaining our efficiency at the highest possible standard, so that all foreign services may recognize the fact that our officers and men are thoroughly keeping pace with the ideas and inventions of the time, and are prepared to do the utmost possible with the means at their command.

NAVAL INSTITUTE, WASHINGTON BRANCH.

APRIL 19, 1883.

PROFESSOR J. RUSSELL SOLEY, U. S. N., in the Chair.

DISCUSSION.

PRIZE ESSAY, 1883. BY LIEUT. CARLOS G. CALKINS, U. S. N.

HOW MAY THE SPHERE OF USEFULNESS OF NAVAL OFFICERS BE EXTENDED IN TIME OF PEACE WITH ADVANTAGE TO THE COUNTRY AND THE NAVAL SERVICE?

THE CHAIRMAN.—Before proceeding with the discussion of the admirable essay of Lieut. Calkins, to which we had the pleasure of listening three weeks ago, it may be worth while to summarize its leading points.

The essay starts out with a statement which underlies the discussion of the whole subject, namely, that the Navy can never obtain the support which is necessary to prepare it for the highest usefulness in time of war, until the importance of its services in time of peace is admitted. This main fact lies at the root of the whole question. It shows the reason why this subject was presented for discussion as the subject for a prize essay. It may be suggested that the object of a navy is to fight; that the true purpose, end, and aim of the work of the naval profession is war. How is it then that the question arises as to what work should be done specifically by naval officers in time of peace, other than that of preparing themselves for war? The answer lies in the statement of Lieut. Calkins, which is so well set forth at the outset. In order to reach its highest activity during war, the Navy requires support and encouragement from the community and from the country. At present the Navy does not get that support; and it can be obtained only when the community is forced to see that the services of the Navy in time of war and in time of peace, at all times in fact, are of the highest value to the country.

In discussing the general question, the writer lays down three broad principles in regard to any kind of work that should be done by naval officers in time of peace. The first is that it should be useful; the second, that it should develop responsibility; and the third, that it should have a direct application to the demands of the naval service. In specifying the particular lines of activity that naval officers should follow, the writer occupies the second part of his essay with a discussion of the training which it is necessary that naval officers should have to fit them for their work. In this connection, Lieutenant

Calkins takes up the subject of the higher education of officers. He refers to the two ways in which this education may be given: either by an institution established on a formal basis, similar to that of the Naval Academy, except that it would be for purposes of higher education, as the latter is intended for preliminary training; or by such arrangements as shall give to officers the fullest and freest opportunity to acquire knowledge and to improve themselves under the direction of a central organization with a central head, when they please, where they please, and as they please. It is evident that the preference of the writer is for this second form of naval education. Having treated that question, he takes up specifically the branches of study that should occupy the attention of officers; first, the scientific branches, then the more general group of studies, including history, political economy, and international law. In the third part of the essay the writer refers to the particular departments of the public service in which officers may find useful employment in time of peace; and therein he treats of the Lighthouse Establishment, the Coast Survey, the Revenue Marine, the Life Saving Service, the Fish Commission, and, at some length, of the Mercantile Marine,—a subject on which he is specially qualified to speak,—the Steamboat Inspection Service, and Preservation of Harbors. The fourth part of the essay is devoted to an investigation of the lines of strictly professional work that a naval officer may take up with advantage to himself and to the public service generally; and here the writer dwells upon a very important subject, as it seems to me, one of the most important in the essay, that of increasing and improving the training of officers specifically for war. He points out the singular fact that but little is done at the present time in the way of training officers directly for war as war is understood to-day; and he calls attention to the importance of enlarging the professional course at the Naval Academy, by adding to it a thorough analysis of the work done in the last war. He also takes up and treats at some length, and with considerable detail, the subject of improving the condition of the men, their education, the furnishing of libraries for the crews of ships, and the work that officers may do in this particular connection. In the same part of the essay, allusion is made to the labors of the Naval Observatory, of the Hydrographic Office, of the Office of Naval Intelligence, and to the work accomplished by the officers detailed as instructors at the Academy, whose occupation secures for them a most valuable post-graduate course.

In conclusion, the essayist takes up the subject of rewards for meritorious effort, and in this connection he condemns the English system of giving rewards by increased pay, and also the system of rewards by promotion outside of the regular turn. The conclusion that the writer reaches seems to me a somewhat discouraging one. It is practically that virtue is its own reward, and that officers must look for compensation for the efforts which they make in the special directions described by the essay, in the consciousness of well-doing that good work always brings with it.

The essay makes a strong appeal to the patriotism of officers, and presents an earnest argument in favor of their taking up some of these useful branches of investigation and of labor.

The essay is now open for discussion.

Assistant Naval Constructor F. T. Bowles.—It seems to me very important that naval officers should realize the actual force of this essay, which unintentionally represents the utter ineffectiveness of our naval force.

I say this because the very existence of this essay indicates the presence of an unhealthy state of affairs; for, scanning the Navy as it stands at present, comparing the high education already received by our officers with the degraded, inefficient condition of the men, the examples of modern naval construction with our antiquated *matériel*, it is evident that something is lacking when the remedies here suggested would all be the natural outgrowth of an energetic and well-supported naval service.

It must be astonishing to one unacquainted with the Navy to find so many remedies proposed.

Now, every one will acknowledge the proposition that a navy is an important adjunct of a government which wishes to extend abroad its influence in art and civilization. Taking this for granted in connection with the fact that the Navy receives little support from the country, we must acknowledge that we have no foreign policy—that is, apart from considerations of the diseases of cattle and the protection of Irish citizens abroad.

Until we assume some definite attitude towards foreign powers, and until we enforce respect and attention to our influence, the Navy can have no real importance.

I think that the whole spirit of the people of this country is a militant one and entirely in favor of the Navy. A gentleman whose business it was to read many small newspapers published in various parts of the United States, which really represent the feelings of the democracy, told me that during Mr. Blaine's term of office as Secretary of State, the spirit of the country was in favor of his policy, which would have been the making of the Navy. That is a remarkable fact, considering that our government, as it stands at the present, has no such support; and I mean to say that the real spirit of the people in regard to our foreign relations, and therefore in regard to the Navy, is entirely misrepresented, or unrepresented in the government, where considerations in regard to the Navy are deemed of least importance. Then, coming to the fact that we have obtained only limited support from the country—fifteen million dollars per annum—the question is asked, What have we done with it? and the answer is, nothing. That, of course, reflects upon the Navy, particularly on the Navy Department.

Lieutenant R. Wainwright.—While I most heartily agree that the essayist has shown the advantages, in fact the necessities, of higher education, there are some details of his scheme with which I can find fault. In attempting to draw up any scheme of education, especially of post-graduate education, or of higher education, it is necessary to look to the education of the mass.

Genius can look out for itself. In spite of obstacles, genius will certainly rise triumphant, and I believe that there is no force which will enable those who are incapable to become efficient. Therefore, I think the fault of this scheme is that it is a project mainly for those who are already students, men

already capable of guiding their own studies. While it does give to officers advantages that they may not have now, it does not point out the method of raising the standard of intelligence. In such a scheme I think a course of lectures should be inaugurated at the Naval Academy. I think anything that may be done to foster our Alma Mater should be done. By a course of lectures at Annapolis there would be additional employment for its large staff of instructors, and there would some good come out of it which would show for the large expenditures now made. At the present time there is a small showing for the expenditure, on account of the limited number of graduates allowed to go out from the Academy. I believe such a course of lectures with the aid of a number of specialists may be made useful and valuable. While officers might be required to attend these special lectures, very little of their time need be so employed. I think those already students would find no difficulty, with the aid of the library and other facilities provided at Annapolis, in using their time with advantage to themselves; and those not studious must at least be benefited. After such a course I would give all the latitude that is mentioned in the essay; but I think even then that the claims of the Torpedo Station and the Naval Observatory should not be overlooked with this object of higher education in view. I believe that certain branches of instruction can be carried higher there than in any special course at a university.

In regard to the proposed annual essay, I must wholly differ with the gentleman. I think it is very impracticable. It seems to me that in no body of men can the greater number write well, and in the majority of cases naval officers would write badly; anything required to be written by force and precedent will necessarily be carelessly done,—will tend to lower the standard of education, and tend also towards deterioration. I can hardly conceive of a sadder fate than that of those unfortunate officers who would be required by the mandate of a cruel department to read over a mass of annual essays such as this paper contemplates.

Lieutenant F. Winslow.—I regret that I was not present when the Prize Essay was read, as I should have liked to have heard the discussion that ensued; and I am equally anxious to hear all that can be said upon the subject to-night. But before further discussion by other members, I should like to call the attention of the Institute to some of the essential features of the essay and to the bearing they have upon the future.

We have now had four Naval Prize Essays. They have been written on subjects widely separated, but they have all possessed several common features. They have all been radical in the remedies proposed, and have all covered extensive ground. Particularly is this true of the first and last. These have proposed schemes neither practical nor practicable.

To my mind this essay is a most extraordinary production. A scheme for the improvement of the naval officer which not only considers his moral, financial, and literary status, but which also includes the hygienic and hydrographic conditions of our rivers and harbors, is a matter for some amazement. But the proposed general upheaval of the established customs of the service and

country is still more remarkable. The essay extends from the belly of the sailor-man to the Constitution of the United States. I can think of nothing I have ever read that has the same scope, unless it is Punch's "History of Motion," which was to begin with the "first revolution of the earth, and take everything in its turn." Now, it is manifestly impossible for any one to criticize an essay of this description in one evening. I can pick out a few good or bad things, here and there, in the course of half an hour, but the discussion under those circumstances will have no serious weight in forming other men's opinions. I will not, therefore, attempt elaborate criticism, but, after running over a few particular points, I will call the attention of the Institute to certain principles upon which the essayist bases his conclusions, which are, to my mind, radically wrong.

The essay renews certain recommendations contained in the last report of the Secretary of the Navy; that is, the transfer to the Navy Department of the Bureaus of Revenue Marine, Life Saving Service, and Supervising Inspector.

I do not know that any one claims that these bureaus are not working to the satisfaction of the country. There may be faults in their administration, but they are not so great that they have raised a hue and cry; and whatever faults do exist, I think there is a very prevalent opinion among the people that there are faults infinitely greater in the administration of the Navy Department. We occupy a very peculiar position in asking for the transfer of these bureaus. We are like men in a boat that is leaky, has holes in the bottom, is getting full of water, with the crew at loggerheads and catching crabs; with no one at the helm, or, if there is, no one who knows how to steer. We see boats ahead, well manned, and safely proceeding on their way; and, recognizing our condition, we cry frantically to them to turn and take us in, and not only that, but we insist that we be allowed to take charge of the boats and to manage them. We insist upon grasping the tiller and the oars. Naturally the other crews refuse. Self-preservation would prevent their permitting it. They say, with reason, that we have made such a bad mess of our own affairs that there is danger in entrusting us with theirs. To my mind their argument is a very cogent one. The case stands thus: The Navy has steadily deteriorated of late; we have either had an influence in the affairs of the Navy and the administration of the Navy Department during the last fifteen years, or we have not. I do not say we have, for I think the reverse has been the case; but, however it may be, the inferred conclusions are dead against us and the transfer. If we have had no influence in the administration of our own affairs, what likelihood is there that we shall have any over the administration of the transferred bureaus? If we have had an influence, then we are responsible for the present condition of affairs. The conclusion seems too obvious to need statement, but it will be most forcibly stated if, however, we demand Congressional action; and the result can be readily imagined. But the principal reason given by the essayist for this transfer is, that it would be in the interest of the general education and improvement of the naval officer, and would fit him for some future usefulness. Now it can hardly be expected that Congress will turn over these different bureaus to naval officers for such a reason and as a mere experiment. It may be a good thing that naval officers

should be improved, but the country would naturally wish it to be done in some way less likely to be expensive.

Again, in regard to the employment of a larger number of officers under the Lighthouse Board and Coast Survey. There is no doubt that it would be advantageous if more officers were employed under both, but the primary reason assigned by the essayist for the increase seems hardly a sufficient one. He does not claim that such assignments would promote the efficiency of either service to any great extent, but that the duty would be a means by which the naval officer himself would be advanced, and his usefulness in the *future* be extended. But the Lighthouse Board would, as I should were I in charge of that service, object to the subordination of their special views to the education of naval officers. They do not care whether a naval officer is educated or not. What they wish is, capable officers to manage their tenders and to supervise the operations of the establishment. They have no desire to entrust the superintendence of repairs or the command of steamers to inexperienced naval officers merely to train them or to give them an education. They would naturally object; and therefore in order to accomplish the scheme, compulsory legislation would be necessary; and that, I fancy, would be difficult to bring about.

Again, the essayist says that the Coast Survey, in return for the services of officers and men of the Navy, should see that the officers are instructed in all the various branches of surveying and geodetic work. The objection just stated applies here also. The Coast Survey people will say that there is no particular reason why they should be turned into a board of instructors; that they have nothing to do with the education of naval officers; that they come to them prepared, they suppose, to do a certain kind of work, and if they cannot do it the Coast Survey does not wish them. Certainly it does not wish to instruct them.

I might take up a few more points, but I have not time. Reduce this essay to its essential feature and you will find that it is only a great scheme for promoting the education and mental activity of the Navy. Now, nobody objects either to the education of officers or to the acceleration of their mental processes, nor will any one deny that both are desirable. One cannot object to the statement of a general principle. If a man says that sick people need medicine, one cannot find fault with the statement. It is only when he states the specific remedy that should be applied to the disease that one can take exception. Therefore, while I must agree with the essayist in thinking that disease exists, I decidedly disagree with him as to the remedy he proposes. Look through the essay and you will find that this proposed remedy is an extensive system of study and investigation of everything of interest and importance to the civilized world, with, perhaps, a slight leaning in favor of the interests of the naval service. Now this system appears to me not only wrong, but impracticable. The essayist proposes a Director of Studies who is to decide what study each officer of the service is to take up, basing his decision upon the character and fitness of the individual for any special branch. This would require an intimate acquaintance with every officer in the service. I do not know how many officers there are—some two or three

thousand, I think—but it is certainly as much as any one man could do to become acquainted with them all. But that is not all this Director would have to do, by any means. After achieving intimacy he must direct their studies into such channels as their personal qualifications would seem to render advisable. A "thoroughgoing specialist," however, is to be allowed full liberty in the selection of his study.

Now, it is hardly possible that any one urging this can have carefully considered what this Director of Naval Studies is to be. He is to be a master of all arts and sciences—for there is no limit to the subjects the naval officer may take up. For instance, the Director must have a knowledge of navigation, gunnery, seamanship, steam engineering, and all the collateral branches of the naval profession. That would seem enough, but the plan of the essay contemplates much more. It is especially advised that study and investigation of matters in no way connected with the service should be pursued. The Director, then, must understand the arts and polite literature, law and political economy, and all the sciences ; for he is to be prepared to follow the "thoroughgoing specialist," whatever such individual may be, wherever that "thoroughgoing specialist" may take him. Now, the arts and sciences are pretty wide, and very few men in this day undertake to master more than one of them, or even part of one. But the Director must be master of all. In science he must be not only an anthropologist, but an ethnologist, an ethnographist, a heliologist, an archæologist, and a philologist ; not only a zoölogist, but also a histologist, embryologist, homologist, morphologist, anatomist, and palæontologist. He must be a chemist, botanist, and electrician ; must be familiar with branches without end—subjects innumerable. He must be prepared for all things ; for the thoroughgoing specialist may drag him from the solar system after its disarrangement by the repulsive force of the sun, to the minutest details of quantitative analysis. Suppose he is carried, as he may be, into zoölogy ; from the general science into one of the branches, say the invertebrates ; from the invertebrates into one of the four great groups ; thence into the orders numbering tens and twenties in each group ; thence into the classes numbered by hundreds in each order ; from classes to genera ; from genera to species or varieties numbering hundreds and thousands to each genus. This Director must know them all ; must be prepared to elucidate any question ; and, Mr. Chairman, it is possible that he may be torn from the contemplation of the legs of an Apollo or the arm of the Venus of Milo to the study of the alimentary functions of the *Gregarinidæ*, which are parasites of the intestines of the common tape-worm.

Now, it is possible that, through the operation of the laws of evolution and survival of the fittest, we may get, in the course of time, an omniscient Director. But it seems hardly possible that in the present day, or in the lifetime of any here present, such an intellectual giant will be produced. But aside from the evident impossibility of carrying out the plan so far as the Director of Studies is concerned, is the remainder possible ? and, if possible, would it be of advantage to the service ? As a matter of fact an officer can, at the present time, study anything he pleases ; he may write as many essays or make as many collections as seem to him desirable. But how many do so ? And, if few are

so employed now, has the essayist proposed any method for increasing that number? I find that there is little or no important change contemplated in the present detail of officers, except that more are to be employed in the Coast Survey and other establishments. And as the same force is to be kept at sea as at present, whence is to come the corps that is to be devoted to study? Is it supposed that many officers will voluntarily take up additional work without additional reward? Such has not been our experience in the past, and there seems no ground for believing it will be changed in the future. The new order of things is partly compulsory, partly optional. No reward is offered for a good essay; no punishment for a bad one. The officer is to be allowed, or ordered, to do something, or anything. We see how large an amount is accomplished when the work is optional; and though the quantity may increase when it is compulsory, have we any right to expect more than perfunctory work under such circumstances? and of what value would that be? No man has reached eminence in any profession in the world by occasional application only. You will find that the great leaders in science, art, or literature have become so only when they were well on in life, and when their whole previous existence had been one of constant, unremitting labor. It is hardly to be expected, then, that an officer devoting every alternate three years to some profession or science, in addition to more or less naval duty, should accomplish much or become very prominent. He will always be a subordinate, always be considered an amateur, and his labors will tend, not so much to the increase of his own reputation as to that of his master, and not at all to the advancement of the reputation of the Navy. We must realize that our fame and that of the service can be enhanced only by the successful performance of *naval* operations, by work that requires the exercise of our *naval* faculties. By engaging in outside pursuits we may achieve some personal distinction; but it is the man that is distinguished, and not the officer nor the service.

In this hasty review of the specific remedies proposed in the essay, it may be said that, condemning much, I suggest nothing. At this time and place it is not necessary for me to suggest anything. We are met here to criticize and discuss this essay, and, considering its extent and variety, we have not time even for that. Certainly we cannot elaborate a better plan in a half-hour, and I will not attempt to do so; but before I close I would like to call attention to the effect such a course as that indicated by the essay will be likely to have upon the future of the service. Reduce this essay to its essential features and you will find the burden and refrain of the song is—study, write essays, send in reports. The individual officer is to be directed into scientific work, into artistic work, into literature, into almost anything except the study of the naval profession; but especially is he to devote himself to scientific work. Now, are those studies, which are mainly of a scholastic nature, of the kind the Institute believes will conduce to the future efficiency of the officer? Remember that the training of scientific men is wholly different in plan from that of active and practical men. The whole history of modern science shows that a man never arrives at conclusions except, I may say, logically. It is the deductive

method he pursues. In the course of time such a training will naturally make that man study well, not only everything he sees, but everything he does. His authorities must be behind him. Every act, every word, is to be based upon sound postulates before done or said; such is the tendency of his training. But it is necessary that the mind of the military man, and especially of the naval officer, should be trained by a method exactly the opposite. His actions must be apparently intuitive. He must know and do by instinct rather than by mental action. The emergencies that arise with him cannot be easily foreseen. He cannot state even to himself the *pros* and *cons;* such hesitation would make disaster imminent, if not certain.

War, whether on land or on sea, is not an exact science. It cannot be reduced to purely scientific methods. Much, sometimes all, depends upon the courage or audacity of one side or the other, and these factors cannot be eliminated from the problem. If they are, the eliminator will find all his calculations are upset. Yet to just such a course will the scientific and scholastic training lead. Courage, daring, endurance of ships, guns, and men, influence of wind and sea, are factors that, having a variable value, are apt to be discarded by the scientific mind. Accustomed to deal with hard facts, indisposed to admit hypotheses, never taking chances, and coming to a decided opinion only when each successive step has logically and clearly led to it,—the mind so educated is totally unfitted to control operations whose success depends largely upon qualities the importance and value whereof have not been considered. If you will read the history of naval wars and of naval operations you will find that the successful men are those who dared, and not those who reasoned. Their actions were not based on what would be called sound postulates; they were guided by instinct, by intuitive perception. Their conduct was the result of dependence upon factors, influences, whose value was unknown. What they realized was that the laws of war are not immutable, and that the great commander makes, rather than follows, them.

Farragut passed the forts in spite of the advice of all the captains of his fleet, because he *dared* to do it. Nelson attacked the French fleet at the battle of the Nile when the chances seemed all against him; and I fancy if any one looks over the course, he will find success in naval warfare is not so dependent on reasoning as it is on courage, pluck, daring, and ability to take the chances. Now, these seem to me the qualities one should strive to inculcate in the officer, and I doubt very much if it is possible to inculcate them except in the active practice of the profession. I am sure the profession cannot be actively practiced in a studio, or laboratory, or in the pages of a magazine. I agree with the essayist that responsibility is the best experience a man can have, but very much depends upon what the responsibility is and how it is exercised. The man that decides upon the character of a fish or of a work of art does not assume the kind of responsibility that will rest, sooner or later, on the shoulders of the naval officer. The former has plenty of time in which to make his decision, can consult any and all authorities, and no great disaster can follow a mistake. If he is not sure he does not speak, and his risk is reduced to a minimum. The responsibility of the naval officer, however, is wholly

different; it is the responsibility of taking chances—of following one course or another, and it sometimes does not matter which, so long as it is taken promptly—when everything appears against both. Are those trained in the closet likely to assume responsibility of that kind?

Now, one other thing. We people of the Navy are becoming dissatisfied with a position that is a necessity in time of peace. We are beginning to recognize that we are not essential to the Government or country except occasionally. We must also realize that we necessarily occupy subordinate positions except occasionally; and, too, we must remember, when we attempt to change the order of things and the service so as to increase our importance and usefulness in time of peace, that we run very great danger of impairing our efficiency in time of war. We must remember that these days are not our days; not days for the exercise of our peculiar calling. We must be content to bide our time. When that time comes, the man who is the best officer will have been most useful. If his preparation *in his profession* has been thorough, he is the man that will succeed, and to the achievement of such success should our efforts and training be directed. That any one should think otherwise, that any one should hold up to the naval officer as most worthy of his efforts pursuits other than his legitimate one, is to me astonishing. In no other profession can you find such a course advised. If you ask the butcher, the baker, or the candlestickmaker how he can be most useful, he will undoubtedly tell you, by attending to his own business. But if you ask a naval officer the same question, he tells you, by being anything in the wide world except a naval officer. This is a sad commentary on our condition. It is a tacit admission that the Navy is useless in the present, and likely to continue so in the future.

And it is to that future that I would call your attention. When the day comes and we are commanding vessels or fleets, if we experience disastrous failure, if we are whipped and are annihilated, it will be useless to plead in excuse that we have described a new species of bug, that we have discovered a new statue, that we have written essays on polite literature which have been favorably noticed. The people will naturally feel that they paid us to be naval officers, to prepare ourselves for fighting, and to fight successfully, and they will naturally expect us to do what we were paid to do.

I, for one, am unwilling to see such a course adopted in the service as will make the Navy of the future liable to reproach. I do not care for any future historian to paraphrase Macaulay's famous sentence regarding the navy of Charles II. and James II.; I do not wish my descendants nor those of other naval officers to see in the pages of history a phrase like this: Doubtless there were in the Navy of the United States both seamen and officers; but the seamen were not officers, and the officers were not seamen.

Lieutenant W. H. H. Southerland.—While I do not agree with all that is contained in the essay, I must say that I almost wholly disagree with the gentleman who has just finished speaking. In his discussion he has certainly gone to an extreme. In a long speech, he has found fault with everything

contained in the essay, but has failed to make any suggestion in regard to the subject-matter. He considers the essay to be "impracticable and unpractical." I must admit that it may seem so on first glancing over it, but a careful consideration of some of the various means proposed will cause us to admit their practicability in some degree.

In the discussion of this essay I trust that feasible means of carrying out some of the suggestions contained in it will be proposed, and that they will meet with the approval and consideration of the Department.

It is useless to say that any one person can be found to perform the duties of the proposed Director of Studies, but I see no reason why we cannot have in each branch of our profession, and under certain circumstances, an officer who can perform the duties of Director of Studies for that branch. At the Naval Academy each head of a department is a Director of Studies for his own department. At the Torpedo School the Superintendent assumes the duties of a Director of Studies pertaining to torpedo warfare.

Now, as to the opportunities for improvement by study. A post-graduate course at the Naval Academy is certainly practicable. At the present time each officer who is there on duty is, in reality, taking a post-graduate course. Naval cadets, after their two years' service afloat, should be permitted to take a post-graduate course at the Academy for two academic terms—one academic year. Officers of higher rank, who do not care to become instructors, but who desire to take an advanced course in any branch taught at the Naval Academy, should be ordered there for one or two years. Every facility for improvement should be afforded them. Should any fail to take advantage of their opportunities, the Superintendent would find the Department ready to order them away. The length of the term for instruction at the Torpedo School could be increased to one year, and the same plan carried out there that I have suggested for the Naval Academy. A few of those cadets who have no desire to take a post-graduate course at the Naval Academy or at the Smithsonian Institute, could be ordered to the Naval Observatory for a few months in order to learn the practical use of the various instruments at that place. Of course, all this should come during an officer's term of shore duty, and nothing should excuse him from going to sea in his regular turn.

I think that many officers seek to improve themselves while at sea, and I wish to call your attention to the fact that much can be done in the way of improvement on board ship. Each sea-going vessel in our service has at least one graduate of the Torpedo School on board. It only requires an order from the Department to have this officer instruct the other line officers of the wardroom and steerage in the practical use of torpedoes. This can be done while at sea, and it would result in giving each line officer in the Navy some practical idea of torpedoes, and would be an excellent preparation for the advanced course of instruction at the Torpedo School.

I do not take it for granted that Lieutenant Calkins really means to go to an extreme in the matter of study. I think he simply desires to open every possible means for an officer's improvement. For my own part, I think this improvement can be obtained on board ship and at shore stations, in the line

of the legitimate duties of a naval officer. I think the Department should put it in the way of officers on shipboard to learn all that may be of practical use during a cruise. Lieutenant Calkins mentions photography as one of his useful studies. Let the Department put a photographic outfit on each vessel of the Navy, and commanding officers will always be able to find young line officers ready and willing to learn its use. They can easily make the emulsion and prepare their own dry plates, and, with a little practice, can take views of prominent headlands and coasts on a survey, or of anything that may be of professional interest. They may not succeed in making excellent photographs at first, but they will improve with practice.

The Department now has it in its power to give young officers some little chance to handle vessels. Any young lieutenant would be only too happy to have the command of one of our Navy Yard tugs. Such command could be of a year's duration, in which time any young officer of intelligence and zeal would gain much practical experience.

The gentleman who preceded me spoke of Farragut and Nelson as instances of great naval commanders who acted by instinct alone. Every student of naval history will say the contrary. Reason, not instinct, convinced Farragut that some of his vessels were sure to pass the forts; that the forts could not keep up a fire that would sink all his fleet. It was not instinct that led Nelson into the battle of the Nile. He knew what English sailors and English ships had done in the past, and he reasoned that they could be trusted to do the same again.

Lieut. Winslow is averse to the transfer of the Coast Survey to the Navy Department. I think that the law which now prevents the Navy Department from doing the hydrographic work of our own coasts should be repealed. I am sure that the essay makes it very plain that officers of the Navy should know our own coasts, and only in the Coast Survey can they obtain a full knowledge of it.

LIEUTENANT J. R. SELFRIDGE.—I came here this evening with no intention of taking part in the discussion, but there is one point that has not been touched, upon which I desire to say a few words.

I think the impression received after reading the essay is, that in time of peace we should devote ourselves to such studies as will produce the best possible effect on the public mind, even taking up subjects that have no bearing upon our naval education, and which do not tend to perfect our knowledge of professional duties. The highest aim of a naval officer should be to govern his men, to handle his ship in a seamanlike manner, and to possess a thorough knowledge of modern warfare.

We require as good seamen now as in the old days—yes, even more so; and the officer who desires to stand at the head of his profession must make his mark as a good seaman.

I regard the higher order of specialties as accomplishments, which are of minor importance compared with the grander duties that lie directly in our path. I think, therefore, it would have been better if the essayist had dwelt

longer on this point, and had given greater prominence to our professional duties, which, as the Chairman has just stated, are fourth in order of divisions into which the essay is divided.

The subject of fleet manœuvres is dismissed in almost a line. I think this is a very important subject, and one that can be studied with greater profit to ourselves, than can a new professional specialty,—natural history, for instance.

The naval officer of the present age can keep pace with the improvements of the day only by constant application, and I believe his time will be fully occupied in pursuit of legitimate work, so to speak, without stepping aside to seek for knowledge that can be of no practical value to him as a naval officer, or to the country at large.

Ensign W. I. Chambers.—I am very much interested and instructed in listening to the discussion of Lieutenant Calkins' valuable essay this evening, and wish to add a few remarks on a point that seems to me to have been somewhat slighted. The time already consumed in the discussion makes me hesitate to prolong the meeting, and induces me to maintain silence; but as this discussion will be read by many in its printed form, I should like to add a few words, if possible, even at this late hour.

In the essay, the special study of international and municipal law, political economy, and social science, is recommended, and I wish to say that I think the pursuit of these studies would not only tend to develop qualities very requisite in every officer, without detriment to his other professional attainments, but would also prove of the greatest value to the naval service and to the country. By familiarizing officers with the needs of the nation, we should enable them to take an active part in establishing and maintaining with credit a settled policy, of which the country stands so much in need. And it seems evident to me that in the pursuit of these studies the mass of naval officers themselves would become convinced that the maintenance of a navy commensurate with the best interests and dignity of the nation is an actual *necessity.* When officers become so convinced and are able to explain intelligently their ideas to the great mass of citizens and legislators with whom they are constantly brought in contact, we may hope to have at least a *matériel* in the maintenance of which officers will find ample opportunity to obtain much coveted practical experience in the handling of modern ships, and to keep pace with the constantly progressing requirements of a modern naval officer.

I am a firm believer in these three principles: (1) naval superiority or excellence and commercial prosperity go hand in hand; (2) commercial prosperity is vital to the best development of our country and to the happiness of its people; (3) both naval excellence and commercial superiority are necessary factors with us, if we are to maintain our peace with all nations or prevent future embarrassment and financial ruin, which are inevitable results of a long-continued weak and decaying condition.

Now, I believe also that it is within the power and province of the naval officer to bring about among the people an understanding of these facts; and when the thinking portion of the nation becomes satisfied of the advantages to be de-

rived from the maintenance of a navy, it will become an easy matter to construct one.

It may seem absurd to some that I should imply that the views of all naval officers are not well settled as to the importance of a navy in time of peace, but I have come to believe that they are not, from conversations with many officers on the subject.

In one instance I was told by an officer, whose opinion and ability to express himself made his ideas usually highly respected by his shipmates, that after due deliberation he had come to the conclusion that the United States needed no navy, and that wars with us were a thing of the past. I promptly replied that if I could bring myself to think as he did I should consider I was leading a worthless life and feel disgraced by holding a commission in the naval service.

I have also been told by intelligent men of good social and political standing, men living not in the far West, but very near that proud commercial centre, New York City, that they considered the Navy a useless burden on the public funds, and that naval officers were created only to draw their salaries.

Such views as these often arise from pardonable ignorance, which the naval officer, if properly informed, may be able to correct, and which he should correct.

Briefly, if we expect to fit ourselves for the requirements of modern warfare, in time of peace, we can do it with advantage to the service and country by increasing our knowledge of "*affairs*," and by consequently extending our influence with the people, to the end that a creditable naval establishment may be created and intelligently maintained.

Lieutenant C. G. Calkins.—Of course it is not my intention to attempt to reconcile all members to my views. When gentlemen begin by finding that the essay is absurd and monstrous in its scope, and that its fundamental principles are wholly wrong, the differences between us are irreconcilable. We have not time to take up fundamental principles. It seems hardly worth while to attempt to modify such views at present. But I must say that a criticism long enough to occupy a very considerable portion of the time taken to read the essay, and which is merely negative and destructive, is not very well calculated to elucidate the subject.

The remarks made by the first gentleman who spoke after the Chairman were somewhat general in their character. The next gentleman made a very definite point, upon which his opinion seemed to differ with what I meant to express. I do not think that it is possible to give a higher education to every naval officer. It is therefore not necessary or proper to apply any of these schemes invariably or uniformly to the whole mass. They must be made exceptional for exceptional cases. They must be made to afford opportunities to people who would use them.

Now, a great deal has been said about the supposed neglect of naval specialties. I do not think that measuring by the foot-rule, or by any other standard, the space given to these subjects, they will be found to have been slighted. What I recommended is that officers be allowed to take up things now neglected; purely naval duties were considered and special attention was called to military duties that I consider to be now almost

wholly neglected. Some people think we do not need any preparation for war.

In spite of the personal courage of the French generals in the war with Germany, those who did not care much about knowledge and military studies, when they came in conflict with the Prussian army, organized upon a scientific basis, were utterly paralyzed in regard to the handling of their troops. They found they had no courage, for they felt that they were ignorant. Von Moltke, who may be supposed to be a practical man, says that the man who feels his ignorance "floats irresolute, and is ready to yield to demoralization." It is impossible for the will to be strong and for resolutions to be formed quickly if the man feels that he is ignorant. If he knows he is ignorant, he is weak; and if he does not know it, the matter is still worse.

Two or three examples of instinctive audacity as opposed to reasoning have been cited. Farragut's attack on the Mobile forts was one of them. He had few opportunities when he was young, but he showed a taste for the cultivation of foreign languages, and was better prepared to use them than almost any officer of his standing in the service. When in Mexico, at the time the French bombarded Vera Cruz, he endeavored to find out what practical lessons could be drawn from their experience, and he endeavored to induce the authorities to make use of his studies and conclusions when we went to war with Mexico. When the Crimean war broke out, he made application to be ordered abroad to study actual naval warfare. That is the kind of post-graduate course he desired; and that is what I recommend for officers at the present day. He wished to go to the Crimea because he thought no officer in the service had studied naval warfare more energetically, or was better prepared by knowledge of foreign languages to acquire information of value to the country and to the service.

The name of Nelson has been brought up. In the first part of the essay I quoted a remark in regard to Nelson by a man who knew him well and admired him very much, from which it appears that from the earliest moment he devoted himself to the study of methods for handling a fleet, to the neglect of the details of the profession then deemed of prime importance. He constantly planned fleet manœuvres. Of course he was a man who knew how to handle his own ship, but, far from devoting himself exclusively to seamanship, he had neglected it.

Some of the detail criticisms require a little attention. In regard to the transfers of various services proposed, of course legislation is required, and I do not think it is easy to get. It is not required for changes in the Lighthouse Service, and the changes suggested are intended particularly for the benefit of that service. It seems to me that when a man goes there now he is a little too old to learn the duties of an inspector, and it would be a great deal better if he had a few years service as assistant-inspector. The Lighthouse Service would be well paid for training their inspectors before they give them authority over such an immense stretch of coast as we have in some districts, where it is difficult for any man to familiarize himself with an inspector's duties.

In the Coast Survey, naval officers are often detailed for duty a second time; and it would be well if the authorities in charge should give these officers a

more varied and more thorough training in the first instance before they are called upon to take charge of a party, with important duties to perform.

In regard to the Revenue Marine and Life Saving Service I have said little in the essay, and have nothing more to say at present; but as to the Steamboat Inspection Service, if there is any satisfaction in regard to its operations, it is due to ignorance as to the way it is managed.

The Mercantile Marine has declined and decayed until few know or care to inquire how it is mismanaged and how its revival is obstructed. When masters and mates of steamers are to be examined, it is absolutely necessary that the examiners should be seamen. At present, no matter where a ship goes, her officers are all examined by men supposed to be shipbuilders or engineers. In England, naval officers are employed as examiners, although the Admiralty is not always able to spare them, for there are ships enough to employ them. If we had the fleet of England we should not be talking to-night about extending the usefulness of naval officers.

I have referred to a number of studies in natural history, languages, law, and to a great variety of things upon which I laid very little stress. It is actually proved that there are officers seeking opportunities of improvement in these branches. I do not think it would be wise as regards the future usefulness of the Navy, that we should exclude officers from such opportunities as they now enjoy. We should, however, have a systematic way of assigning them to various studies. I laid most stress upon matters pertaining to the reconstruction of our navy and the development of our resources in time of war. The Navy must have in it men capable of designing guns, ships, and engines,—work that requires scientific knowledge; at the present day you cannot separate scientific knowledge from practical experience. When it has been done, it has usually resulted in serious complication and disaster. It is not done now by any successful business firms in the world. They go to men who have thorough scientific training in the specialties relating to the work that is to be done.

The subject assigned by the Institute for an essay was one that seemed to me to call for extended treatment; and for the very purpose of inviting criticism I made a number of specifically detailed suggestions that I had not any great time or opportunity for studying or working out, and I am very glad that they have been criticized, as they have been by some officers, with the view to make them practical. Criticism is always welcome; but criticism based upon general dislike of everything proposed does not advance the subject very far. The main point upon which naval officers can have anything to say or do that shall lead to practical and immediate results, is what I treated of in the fourth division of my essay, that is, their extended usefulness in connection with naval duties. I did not talk about seamanship drills or the handling of men, because I considered the usefulness of naval officers in that respect as at any rate recognized.

I may have failed in recommending measures that may be carried out, but it seems to me that one consideration is worthy of attention; that of preparation for military duty. I have rarely seen anything on board ship that looked to me like preparation for warfare. I have seen fleet evolutions and much drill with sails and spars; but it seems to me that if a torpedo attack were to be repelled—

if, for instance, six torpedo boats were to approach a vessel with the preparation now made to resist such an attack, there would be hardly an officer or man who would understand his duty. There is no instruction requiring such drills to to be held, and I certainly think that torpedo attacks could not be successfully repelled unless every man understood what he had to do. It would be doubtful if the ship could repel the attack even then. The men should be exercised with special regard to possible torpedo attacks. Until this is done we can hardly say we are prepared for war or that we are doing anything towards making our ships men-of-war.

The only suggestion made by the gentleman whose criticism went farthest was, that we should have some better system of promotion for the higher grades of the service. Undoubtedly, by a great deal of study—not by hap-hazard legislation—some improvement might be made. But it is better to begin with younger officers, who can combine their studies with their practical duties. I think that is a great necessity and an advantage.

In regard to the practicability of this essay or the schemes recommended therein, I do not know what is practicable in our service. The best authorities state that in the Prussian army a rule similar to the one proposed in regard to military studies and reports is enforced in the most absolute and rigorous manner. No officer who skims over a military question of any importance will be promoted. No general or colonel (through whom these papers are forwarded to the Department) who neglects to study them out and to make a fair scientific criticism, will be advanced or even allowed to retain a command. Such a system enables officers to learn to handle their army in view of the contingencies of war. The thoroughness and value of this system may be seen when we consider that the Prussians were enabled to finish the Austrian campaign in seven weeks, and to destroy the French army in a little longer period. The Prussian army was trained and handled by Von Moltke, who was a scientific man if ever there was one, and who had the experience of forty years of active service to supplement the knowledge acquired by study. The Prussian army is thoroughly and scientifically prepared for war, and it receives that training in time of peace or it could never be ready for war.

The necessity for scientific study of the art of war to prepare men for the duties of command was demonstrated at Sebastopol and at Plevna. At Sebastopol, brave but unreflecting officers could see nothing to do but to sink the fleet and abandon the town as soon as the allies effected a landing. But Todleben went to work with spades and picks, and prepared the town for defence, and held it long enough to save the honor of Russia and to exhaust her enemies.

At Plevna, ignorant and audacious generals sacrificed fifty or sixty thousand men in a series of headlong attacks. It became necessary to send for Todleben, and he came and drew lines around Plevna, shut the Turks up there, starved them out, and captured their whole army with small loss to his own. He successfully carried out modern and scientific methods for investing a town.

These things, it seems to me, show that science and reasoning have their applications in modern warfare. There is no trade, no industry, no business

enterprise of any kind that does not recognize the necessity of scientific men. I am far from hoping that the suggestions of this essay will be carried out in my time, but I think many of them may be elaborated, modified, or transformed until they are made of some use to the service. I really think that I did consider what I was doing while writing. I do not object to a spirit of criticism. If we had had no sharp criticism, the meeting for discussion to-night would have been a complete failure; and the Institute may be congratulated that we have had some active discussion. I am much obliged to those members who have given the paper enough attention to enable them to criticize it.

The Chairman.—In closing the discussion this evening, I cannot help saying that I feel sorry that the most active part of it did not take a more specific direction. The main criticism of the paper, which was a very comprehensive criticism, struck at the general principles that underlie the whole subject, and it appeared to me that it seemed to find some little fault with the writer of the essay for having written an essay at all on this subject. Now, the question before the writer was, How may the sphere of usefulness of naval officers be extended in time of peace with advantage to the country and the naval service? In making a general criticism on the fundamental principles of the paper, it was at least incumbent upon the critic to suggest or to indicate some way in which this particular question could be answered, other than that which is contained in this essay.

With regard to that part of the discussion which touched upon the studies necessary for a naval officer, I may venture to suggest that although scientific study, that peculiar form of investigation which is pursued in the exact sciences generally, particularly in the higher mathematics, may not perhaps be conducive to the kind of reasoning and mental discipline that an officer most needs in moments of critical emergency, yet you must in these days develop men in the special directions for which they are specially fitted. You cannot afford to lose the services of a mathematician, if you have one in the Navy, or again of an accomplished physicist, or of a man who is eminent in any other branch of scientific research, even though his qualifications as a naval officer may not be very materially furthered thereby.

There is one point to be directly considered in all these matters; and that is, the strength that the Navy has in the community and before the country. Now, it is not to be denied, for a moment, that if you produce an accomplished astronomer, physicist, or mathematician in the Navy, the Navy has made an immense gain; that the Navy is stronger before the country. If it produces men able to speak to the scientific men of the country *ex cathedrâ*, in a way that will compel respect and attention, its influence with the country and with the scientific community is vastly increased; and this influence is a thing that it is very important for the Navy to secure.

With regard to the other studies,—the non-scientific studies,—history seems to me particularly useful, because it widens the scope of a man's observation and interest. International law, social science, and municipal law, to which Lieutenant Calkins directed attention, and, more especially, administration and the science of affairs, are matters exceedingly valuable to the naval officer; and

any experience in that direction is a great gain to the Navy. Some allusion was made to the influence that naval officers exert on naval administration. Now, I do not think that anything can promote that influence more than experience in affairs and a knowledge of affairs—a knowledge of the way of dealing with men, a knowledge of business, if you like, a knowledge of administrative work. Occupation in kindred branches of the public service might possibly give officers some experience of a character that they could not otherwise get; and as the subject-matter would be closely allied to their own profession, they would not be losing a day in professional improvement.

As to the question of writing reports, and as to the practice of requiring officers to write, there came into my mind a few moments ago a sentence that occurs in one of the letters of a very remarkable man, whom nobody will deny to have been a great naval officer, a fine seaman, and a man of splendid dash and courage—Captain John Paul Jones. In 1778, I think it was, in writing a letter to the Marine Board at Philadelphia, Paul Jones makes use of these words: "No person other than a gentleman, as well as a seaman, both in theory and practice, is qualified for a commission in the Navy. Nor is any person"—and here is the remarkable part of this statement in connection with the subject of writing reports—"Nor is any person fitted to command a ship-of-war, unless he is capable of expressing his ideas on paper in language that becomes his rank." I think that is strong testimony from a high authority to the usefulness of that kind of practice to naval officers.

I would like to put in a special plea for the study of naval history and biography. I must say I do not think there is anything more useful to a naval officer, after acquaintance with the practical details of his profession, than familiarity with naval operations as they have actually been conducted—with recent operations particularly, if students cannot be induced to go farther back. Naval biography is only naval history from another point of view. There is no better study for the naval officer than to take up the lives of his predecessors, and see the way in which they overcame the difficulties they had to meet. The same difficulties or similar difficulties are to be met with in the future, even though science has changed considerably the art of warfare. I do not see how men in any profession are going to cope successfully with their difficulties unless they study the methods of the masters in the art. Take Sir Philip Broke, for instance; or go as far back as Robert Blake; or take Nelson, or Farragut, or Cushing; or, best of all, take Lord Dundonald, who may be regarded as the typical naval officer, and study each one's career. Even the ablest men cannot fail to profit by studies of this kind.

With regard to the other branches of the government service that have been alluded to, I do not propose to say anything in particular except that the occupation of naval officers, in the direction indicated by the Secretary's report of last year, in conducting all the work of the government upon or in connection with the ocean, would be of benefit to the Navy and to the other services as well. Lieut. Calkins has pointed out in his essay very serious defects in some of these services. If the proposed transfer were made, there is every probability that those defects would be largely removed.

NAVAL INSTITUTE, WASHINGTON BRANCH.

February 11, 1884.

Lieutenant-Commander W. M. Folger, U. S. N., in the Chair.

MACHINE-GUNS. THE GATLING GUN: ITS POSITIVE FEED, HIGH-ANGLE FIRE, AND USE IN WAR.

By Dr. R. J. Gatling.

It requires no gift of prophecy to predict that machine-guns are destined to play an important part in future wars.

They hold the same relation to other arms that the railway bears to the stage-coach, the reaper to the sickle, the sewing-machine to the needle, etc.

Of this class of arms, there is none that excels the Gatling gun in originality of design, rapidity of fire, and capabilities as a weapon of warfare.

The main features of the gun may be summed up as follows:

It has, usually, ten barrels and ten corresponding locks. In working the gun, the barrels and locks revolve together; but, irrespective of this motion, the locks have a forward and backward motion of their own. The forward motion places the cartridges in the chambers of the barrels, and closes the breech at the time of each discharge, while the backward motion extracts the empty cartridge-cases after firing.

The gun is loaded and fired only when the barrels are in motion from left to right; that is, while the handle, or crank, is worked forwards. When the gun is in action there are always five cartridges going through the process of loading, and five cartridge-cases in different stages of being extracted, and these several operations are continuous while the gun is being worked. Thus, as long as the gun is fed with cartridges, the several operations of loading, firing, and extracting are carried on automatically, uniformly, and continuously.

THE POSITIVE FEED.

The earlier model Gatling guns had cartridges fed to them by means of feed-cases, or by a drum, but recently a new method for supplying the cartridges to the gun has been devised, which is *positive and certain in its action.* In the old methods of supplying ammunition to the gun, there was a liability that the cartridges would become jammed in feeding down from the feed-cases into the carrier or receiver; but in this newly-improved feed, the mechanism never loses control of the cartridges from the time they leave the feed magazine until they enter the chambers, are loaded, fired, and the empty cases extracted. With this new feed it is impossible for the gun to fail in its operation, even when it is worked by men unacquainted with its use. This new improvement not only greatly increases the rapidity and certainty of fire, but also enables the gun to be fired at the rate of over 1200 shots per minute, and at all degrees of elevation or depression, which is something no other machine-gun can do. By firing the gun at proper elevations, ascertained by means of a quadrant, the bullets discharged from it can be made to fall upon men behind breastworks or entrenchments, at all distances, from 200 to 3500 yards from the gun. This "high-angle," or "mortar" fire adds greatly to the effectiveness of the gun, and will, no doubt, prove of inestimable value in future warfare.

Experiments have proved that musket-size balls, fired from a Gatling gun at high angles, strike the ground with a force sufficient to penetrate from two to three inches of timber. About 1200 shots per minute can be fired from the gun, raining down a hailstorm of bullets on the heads of men behind entrenchments, thus making such positions, in a short space of time, untenable. Open breastworks, or uncovered entrenchments, would furnish little or no protection to troops against the fire of this formidable weapon. Trials were made with a Gatling gun, having this improved feed, at Sandy Hook, N. J., during the months of July, August, and September, 1882, and in January, 1883, by the United Sates Ordnance Board, composed of the following officers: T. G. Baylor, Lieutenant-Colonel of Ordnance, President of the Board; George W. McKee, Major of Ordnance, and Charles Shaler, Captain of Ordnance.

The following extracts are taken from their report of the trials:

"The object of the experiments was two-fold: first, to test the new feed magazine; second, to ascertain the effect on targets placed horizontally on the ground, at distances of from 200 to 3000 yards, as regards penetration and accuracy."

In speaking of this new feed, the Board say in their report:

"The action is, as claimed in the inventor's description, positive and continuous as long as the gun is worked. The substitution of a positive action for one depending upon the carriage of the projectiles to the grooves of the carrier-block by means of gravitation, modified by friction, is a great improvement. The gun works as well when the feed 'magazine' is horizontal as it does in an inclined or a vertical position. No jamming, or interference of any kind, occurred during the trials, and the rate of discharge varied uniformly with the revolution of the crank necessarily."

In speaking of penetration, the report says:

"The penetration from 3000 to 1000 yards was through two inches of spruce plank, and from three to five inches into the sand, the projectiles striking point foremost."

The gun used in the trials was 45-inch calibre, with barrels 24 inches in length; and the ammunition used contained a charge of 85 grains of powder, and a bullet weighing 480 grains.

In firing at high elevations, to have the bullets strike the ground at various distances, the following elevations were given the gun: At 200 yards range, the gun was fired at an elevation of 88½ degrees, the bullets so fired remaining up in the air 57 seconds from the time they were discharged, until they struck the ground.

At 500 yards range, the gun was given an elevation of 85°.
At 1000 yards range, the gun was given an elevation of 77°.
At 2000 yards range, the gun was given an elevation of 66°.
At 2500 yards range, the gun was given an elevation of 56°.
At 3000 yards range, the gun was given an elevation of 24° 40′.

At all ranges, when the gun was fired at and below 85° of elevation, the bullets struck point foremost, and retained their rotary motion, as was proven by spiral scratches on them, caused by friction in their passing through the boards.

Extracts from the official report of the United States Army Ordnance Board, on the trial of the model, United States calibre (0.45-in.), Gatling gun, at Sandy Hook, N. J., in January, 1883:

The gun is similar in general to the one described in the last report of the Ordnance Board on the subject.

The *lock* is called a rebounding one, the intention being that the firing-pin shall not project in front of the face of the lock until, when released from the cocking-ring, it flies forward and discharges the cartridge.

A device allows the cocking-ring to be thrown out of action at will, and prevents the cocking of the hammers. This is of advantage during drill, and allows firing motion to take place without snapping, and thereby injuring the hammers.

RAPIDITY OF FIRE.

Date.	Kind of Cartridge.	No. of Rounds.	Time.
January 6, 1883.	405 grain bullet.	812	45¼ seconds.
January 6, 1883.	500 grain bullet.	816	45¼ seconds.

The object of the experiments was to test further the new feed-magazine in its adaptability to the use of the service cartridge, both with the 500 and 405 grain bullets, and also to test some new features of the gun and carriage above described. The Board, in its report of October 11, 1882, on this "feed-magazine," when applied to a gun using the English bottle-shaped cartridge, states that it "is all that is claimed for it, and adds very considerably to the value of the gun." In that experiment the gun was fired at various degrees of elevation from 1° to 89°, but in these experiments the gun was fired several times, as rapidly as possible, with 8 and 9 feed-magazines previously filled, and with both kinds of cartridges. The gun was finally dismounted, placed upside down on a staging, and one feed-magazine inserted from below, when the gun was fired with as much facility, and the feed worked as well as when placed on top, showing clearly that its action was positive and entirely independent of the force of gravity. No other feed that is known would operate in this manner, and, though this is an exaggerated case, and one not likely to occur in service, yet it shows how effectually the cartridge is held from the time it is placed in the feed-machine to its delivery in the carrier-block, and how impossible for any clogging or overriding to occur, as is the case at times with other feeds.

T. G. BAYLOR,
Lieutenant-Colonel of Ordnance, President of the Board.
GEORGE W. McKEE,
Major of Ordnance.
CHARLES SHALER,
Captain of Ordnance.

General S. V. Benét, Chief of Ordnance, United States Army, in his endorsement of the above report, says:

"The great improvement is in the feed, which is positive in its action, and 'entirely independent of the force of gravity.' It is believed that the modified Gatling gun, with the new feed, has about reached the utmost limit of improvement."

Extracts from the official report of the United States Naval Ordnance Board on the trial of the new model, U. S. calibre (0.45-in.) Gatling gun, at the Navy Yard, Washington, D. C., January, 1883:

RAPIDITY OF FIRE.

Five drums (each holding 102 cartridges) to illustrate feed action:
No. 1.—Drum emptied in 2.8 seconds.
No. 2.—Drum emptied in 2.6 seconds.
No. 3.—Drum emptied in 2.8 seconds.

No. 4.—Drum emptied in 2.6 seconds.

No. 5.—Drum emptied in 2.6 seconds.

Number of cartridges expended 510.

The mechanism and feed worked well in each case.

Two trials of eight drums each for rapidity and endurance:

First test—Eight drums emptied in 41.4 seconds.

Second test—Eight drums emptied in 42.2 seconds.

Cartridges expended, 1632.

The mechanism and feed worked well.

A supplemental test was here made with members of the Board at the crank, to determine if it be possible to cause an accidental stoppage or imperfect action in the feed by an irregular or jerking method of turning the crank. Two drums, 204 cartridges, were expended in this manner.

The Board were unable to produce any imperfect action in either mechanism or feed.

One drum at 75 degrees elevation. Expended 102.

Two drums at greatest depression (56 degrees) permitted by the mounting. Expended 204.

Two drums with feed 90 degrees to the right. Expended 204.

Two drums with feed 90 degrees to the left. Expended 204.

Two drums with feed underneath. Expended 204.

Total number of rounds fired, 4014.

W. M. FOLGER,
Lieutenant-Commander and Member.
J. H. DAYTON,
Lieutenant and Member.
F. H. PAINE,
Lieutenant and Member.

It is evident that an accurate vertical fire from Gatling guns, delivering a storm of bullets descending under a slight angle of arrival, would, by grazing the superior crest of parallels erected by besiegers approaching a fortification, or those of ordinary rifle-pits or entrenchments, destroy their occupants much more certainly and rapidly than can be done by the shells or case-shot fired from mortars or field-guns. This "high-angle" or mortar fire from a machine-gun opens up a new field in the science of gunnery, and is well worthy of the highest consideration of military and naval men of all nations.

It is well known that the Turks, in the Russian-Turkish war, inflicted great injury upon the Russian forces at long ranges, by firing their muskets at high elevations, so as to deliver what is known as "high-angle" fire; but it is quite evident that in such firing there must have been a great waste of ammunition, for the reason that the infantry soldiers could not well determine what elevation to give their

muskets in order to have the bullets reach the enemy. This great waste would not take place with the Gatling gun, which, being mounted on a carriage, does not move when being fired. A table of distances and elevations being established for the service of the Gatling gun, all that would be required of the men who use it would be to ascertain first the distance at which the enemy was entrenched, and then to give the gun the required elevation (by the use of the quadrant) in order to have the bullets fall within the line of entrenchments of the enemy. The Gatlings could be protected from the direct fire of the enemy by entrenchments or by a pit dug for each gun, so that not even the muzzle of the gun would be exposed.

Among the prominent advantages claimed for the Gatling gun may be enumerated the following: Its adaptation to the purposes of flank defence at both long and short ranges; its peculiar power for the defence of field-entrenchments and villages; for protecting roads, defiles, and bridges; for covering the crossing of streams; for silencing field-batteries or batteries of position; for increasing the infantry fire at the critical moment of a battle; for supporting field-batteries, and protecting them against cavalry or infantry charges; for covering the retreat of a repulsed column; and, generally, for the accuracy, continuity, and intensity of its fire, and its economy in men for serving, and in animals for transporting, it.

It is conceded that small-calibre Gatling guns, which use the service-musket ammunition, will prove invaluable in naval service when used from top-gallant forecastle, poop-deck, and tops of ships-of-war for firing on an enemy's deck at officers and men exposed to view; for firing down from tops upon the roof of turrets; for firing into an enemy's ports; and, in boat operations against an enemy, either for passing open land-works, or for clearing beaches and other exposed landing-places.

Exhaustive official trials of the gun have been made in many countries, under the supervision of officers of high standing, who have strongly recommended its use, both for land and naval service. The reports of such trials are too extended for a paper of this kind.

Gatling guns have been sold, in greater or less numbers, to most of the governments of the world. A few extracts are given of their use in warfare.

In the late Prussian war, the French used the Gatling gun conjointly with the mitrailleuse. From the London *Journal* we clip a correspondent's description of its efficacious use in action:

Up to this time we had not seen any Prussians, beyond a few skirmishers in the plain, though our battery of Gatlings had kept blazing away at nothing in particular all the while; but now an opportunity of its being in use occurred. A column of troops appeared in the valley below us, coming from the right—a mere dark streak upon the white snow; but no one in the battery could tell whether they were friends or foes, and the commander hesitated about opening fire. But now an aid-de-camp came dashing down the hill with orders for us to pound at them at once—a French journalist having, it seems, discovered them to be enemies, when the general and all his staff were as puzzled as ourselves. Kr-rr-a go our Gatlings, the deadly hail of bullets crashes into the thick of them, and slowly back into the woods the dark mass retires, leaving, however, a trace of black dots upon the white snow behind it. This, their famous and historical four o'clock effort, and its failure, has decided the day. That one discharge was enough.

The Russians used Gatling guns in the siege of Plevna. A special correspondent of the London *Times*, writing under date of November 26, 1877, from the headquarters of the army of Bulgaria, at Bogot, says:

The mitrailleurs [Gatling guns] were in constant action until midnight, splitting the air with their harsh, rattling reports. Another account (November 26th) says: The Russians are using their mitrailleurs [Gatlings] a great deal now at night, probably with the intention of keeping the Turks occupied, so as to relax the tension on the infantry in the trenches.

No other arms in the world are equal to Gatling guns for night service. They can be placed in a position in the daytime so as to cover any point desired, and as they have no recoil to destroy the accuracy of their aim, an incessant fire can be kept up during the night with the same precision as in daytime.

In the naval engagement that took place in Peruvian waters on May 28, 1877, between the Peruvian rebel iron-clad ram Huascar, and the British men-of-war, the Shah and Amethyst, a small Gatling gun, stationed in the foretop of the Shah, rendered excellent service.

The correspondent of the *Illustrated London News*, in a semi-official report of the conflict, says:

About five o'clock, the Huascar being clear of the shoals, we seized the opportunity to close. The enemy likewise closed, with evident signs of ramming, firing shell from her 40-pounder. Our Gatling gun then commenced firing from the foretop, causing the men on her upper-deck quarters to desert their guns.

Captain Aurelio Garcia y Garcia, one of the most distinguished officers of the Peruvian navy, in his account of the above engagement, says:

The firing became even more severe from the English frigates, and, as the distance between the antagonists had been reduced to two cable-lengths, more or less, the Admiral brought to bear all his attacking forces, which, on board the Shah, were very formidable in character. From the tops, a Gatling gun threw a hail of bullets at the decks of the Huascar, together with steady volleys of musketry and rifles.

Another account from Peruvian sources says:

A small Gatling gun stationed in her tops very seriously incommoded the combatants on the ram, and her smoke-stack is riddled with bullets.

It is evident that Gatling guns, when used on shipboard or in tops of war-vessels, would be of inestimable service in firing into the port-holes, or in clearing the decks of the ships of the enemy.

THE NAVAL FIGHT OFF IQUIQUE, PERU.

New York Times, July 20, 1879.

The Huascar attacked us again, directing her bow to the middle of our ship. I steered to prevent the shock, but our want of speed made it impossible, and the iron-clad struck our vessel midships. In that moment, Lieutenant Serrano, followed by a dozen sailors, jumped on the deck of the Huascar, and they were all killed by the shots of musketry and Gatling guns fired from the turret, and behind the parapets of the stern.

THE CHILENO-PERUVIAN WAR.

New York Herald, December 17, 1879.

A letter from Lima, describing the defeat of the Peruvian army, at San Francisco heights, says: "The earthworks were defended by a strong Chilian force, plentifully supplied with Krupp field-pieces and Gatling guns. Here Buendia committed the error which has cost the allies the best division in their army. Instead of making a detour, which he could easily have done, and thus compelling the enemy to descend to attack him in the pampa at the rear of the hill, or submit to having his communications with Pisagua cut off, Buendia gave the order to charge up the rugged hill and carry the works by storm. The attempt was gallantly made. Three times the shattered regiments, which had undertaken a feat which it was impossible to perform, were compelled to fall back and re-form, leaving the hillsides thickly covered with their dead and dying, who had fallen in masses before the Krupps and Gatlings long ere they could make their rifles tell."

THE ZULU WAR.

London Army and Navy Gazette, February 22, 1879.

The Gatling guns, landed with the naval contingent from the Active and Tenedos, have astonished the Zulus, who have been trying an engagement with our blue-jackets. They found the fire much too hot, and the naval force

has had the satisfaction of carrying more than one contested position. It is a pity that Gatlings are not more plentiful with Lord Chelmsford's army. The naval brigade have got some, but the artillery have none. If there had been a couple of Gatlings with the force annihilated the other day, the result of the fight might have been different, for Gatlings are the best of all engines of war to deal with the rush of a dense crowd.

FROM OUR SPECIAL CORRESPONDENT.

London News, August 22, 1882.

I have returned from Chalouf, fourteen miles up the canal, where I witnessed the conclusion of a fight in which 250 men, including the 72d Highlanders, with the blue-jackets and marines from the gunboats Seagull and Mosquito, brilliantly defeated a force of twice their number. The fighting lasted from eleven until nearly five. The Gatling guns, in the tops of the gunboats, worked with admirable precision, doing much execution among the enemy, who had advanced to within 100 yards of the canal-bank.

New York Herald, August 26, 1882.

In a telegram dispatched at 2 o'clock this morning, General Wolseley adds: "I omitted to say that I had with me, yesterday, two Gatling guns, worked by seamen, who did their duty admirably."

London Broad Arrow, September 2, 1882.

On all sides it is acknowledged that the Gatling has proved itself an effective arm of service in the present campaign. At Chalouf, and at Mahuta, the naval Gatling was admirably served by our blue-jackets, and afforded "invaluable assistance." Indeed, it may be broadly affirmed that, in the encounter with the enemy at the former place, the results attained were chiefly ascribable to the action of the Gatlings from the tops of the gunboats Seagull and Mosquito. One hundred and sixty-eight Egyptian soldiers, out of 600 which composed the outpost, were placed *hors de combat*. Under these circumstances, it is not unlikely that Sir Garnet Wolseley will employ Gatling batteries extensively in future operations.

London Army and Navy Gazette, October 14, 1882.

The naval machine-gun battery, consisting of six Gatlings, manned by thirty seamen, reached the position assigned to it in the English lines on September 10th, and, on Tuesday, September 12th, received orders to advance. They came within easy range of the Tel-el-Kebir earthworks, and observed guns in front, guns to the right, guns to the left, and a living line of fire above them. Nothing daunted, the order, "action-front," was given, and was taken up joyously by every gun's crew. Round whisked the Gatlings, r-r-r-r-r-rum ! r-r-r-r-r-rum ! r-r-r-r-r rum !—that hellish noise the soldier so much detests in action, not for what it has done, so much as for what it could do, rattled out. The report of the machine-guns, as they rattle away, rings out clearly on the morning air. The parapets are swept. The embrasures are literally plugged with bullets.

The flashes cease to come from them. The Egyptian fire is silenced. With a cheer the blue-jackets double over the dam, and dash over the parapet, only just in time to find their enemy in full retreat. That machine-gun fire was too much for them. Skulking under the parapet were found a few poor devils, too frightened to retire, yet willing enough to stab a Christian, if helpless and wounded. The trenches were full of dead. But few wounded were found. Captain Fitz Roy led his men most gallantly, and followed up the retreating foe until the main camp was reached. Here the halt was sounded. Admiral Sir Beauchamp Seymour and staff now came up and addressed the battery, complimenting the officers and men on their gallantry.

LORD CHARLES BERESFORD ON MACHINE-GUNS.

London Army and Navy Gazette, November 4, 1882.

In my opinion, machine-guns, if properly worked, would decide the fate of a campaign, and would be equally useful ashore or afloat. When the Gatling guns were landed at Alexandria, after the bombardment, the effect of their fire upon the wild mob of fanatic incendiaries and looters was quite extraordinary. These guns were not fired at the people, but a little over their heads, as a massacre would have been the result had the guns been steadily trained on the mob. The rain of bullets, which they heard screaming over their heads, produced a moral effect not easily described. I asked an Egyptian officer, some weeks afterwards, how on earth it was that Arabi, and his 9000 regular troops, who were within five miles, did not march down upon the town in the first four days after the bombardment, when Arabi knew that Captain Fisher's Naval Brigade, which held the lines, numbered less than 400 men. The Egyptian officer replied, "That he knew no army which could face machines which 'pumped lead,' and that as all the gates were defended by such machines, as well as having torpedoes under the bridges, such defences could not be faced." This certainly was the case. I believe the Egyptian officer spoke the truth, and that the moral effect produced by the Gatlings on the people in the first landing prevented the army from attacking the diminutive force which held the lines afterwards.

Replying for "The Navy," at a dinner of the Cutler's Company, Lord Charles Beresford said:

The great value of machine-guns has also been shown. With the Gatlings, the landing parties had cleared the streets of Alexandria and prevented Arabi from returning, and, if they had been allowed to land immediately after the bombardment, they might have dispersed the crowds laden with loot, have captured Arabi, Toalba Pasha, and other leaders, and saved the town; but the government had promised that no man should land, and they were bound by the promise.

Notwithstanding these favorable comments, showing the great value of the Gatling gun in warfare, this distinguished officer, in a paper on

Machine-guns, read before the Royal United Service Institution, Whitehall, London, takes occasion to criticize the Gatling gun, and point out what he claims to be its defects. He says:

Revolving machine-guns are excellent in their way, and we owe the father of them, Dr. Gatling, a great deal for his valuable invention, but their principle invites an accident; they have to do five things nearly simultaneously, any one of which by going the least bit wrong interferes with the other four, and the gun is instantly out of action. The five things are:—revolving the lever, revolving the barrels, loading the gun, withdrawing the empty cylinder, firing the gun—all to be done nearly simultaneously.

Now the casual observer would hardly suppose that all machine-guns have to do substantially the "five things" spoken of; for instance, the Nordenfeldt gun has to have the lever moved forward, which moves the breech supports towards the barrel chambers, which push the cartridges in front of them; then the breech is locked, the cartridges fired, the lever moved backward, the breech unlocked, and the fired cartridge-cases extracted by the retiring breech-plugs—all of which "things," or movements, have to be done quickly in order to obtain rapidity of fire, whereas the simple movement of revolving the crank loads and fires the Gatling gun.

There are several valuable features of the Gatling gun that should not be overlooked; for instance, a ten-barrel Gatling gun fires ten times in one revolution of the group of the barrels. The action of each part is therefore quite deliberate, while collectively the discharges are frequent. Another valuable feature in the Gatling is, that the cartridges are fed into the carrier at the top, and are carried around to the under side of the gun before they are loaded and fired. Thus, it will be seen, the point where the cartridges are fired is far removed from the supply of cartridges used in feeding the gun, so there is no liability of the escape of gas, which may occur by the bursting of the head of a cartridge, and which might communicate with the magazine, causing a dangerous explosion. Most other machine-guns have their magazines, used for feeding cartridges to them, placed in close contact with the firing-point, hence the liability of premature and dangerous explosions. Several accidents of this kind have occurred, resulting in death to the operators of such guns.

The Gatling gun is dangerous only to those in its front.

Sir Garnet Wolseley, in discussing the subject of machine-guns, has expressed his conviction that the general, who, in the next big war, utilizes machine-guns to the best advantage, will have an immense opportunity to gain great fame.

Machine-guns are closely allied to metallic cartridges, which are of modern invention. Without the latter, the former would be of little use.

The art of making metallic cartridges is now so well understood that they work perfectly, and their use makes the machine-gun of immense practical value.

The French mitrailleur did not use metallic cartridges. It used paper-cased cartridges, which were imperfectly made, and this fact, coupled with the imperfection and great weight of the gun, together with want of skill in its use, led to its failure.

The same class of men who doubted that rifle-guns would ever take the place of the smoothbore, and who declared that the breech-loading musket would never supersede the muzzle-loader, object to machine-guns. Their objections are, that such guns are liable to get out of order, and to become disarranged, by means of a hostile shot, lack of care, ignorance in management, or from similar causes, etc.

Without defending machine-guns in general from these objections, it may be said that the simplicity of parts in the Gatling gun, the protection given to the working mechanism, and its absolute working, make it as secure from accident as any gun can well be, even if it be worked only by brawny hands.

A trial of a 0.50-inch calibre Gatling gun (old model) was made at Fort Madison, Maryland, in October, 1873, under the supervision of the late Lieutenant-Commander J. D. Marvin, U. S. N.; during the trial 100,000 cartridges were fired, and of this number 63,600 were fired without stopping to wipe out or clean the barrels. The Official Report says:

> "The working of the gun throughout this severe trial was eminently satisfactory, no derangements of any importance whatever occurring."

Surely, such a severe test should prove that the Gatling gun is not liable to get out of order.

The value of an invention is to be determined by the results it can accomplish. The Gatling can fire more shots in the same space of time than any other gun. With it, three men can do the work of hundreds armed with ordinary guns. Its use will, to a great extent, supersede the necessity of large armies; hence its use will be in the interests of economy.

It is evident that in the future wars are to be waged with all the aids that modern science can afford, whether they are the results of the

discoveries of chemists, or of the inventions of mechanics. The record of wars and isolated engagements in which the Gatling gun has borne an important part within the last fifteen years, is sufficient to establish the value of machinery in warfare, and the superiority of the gun over the ordinary individual arm.

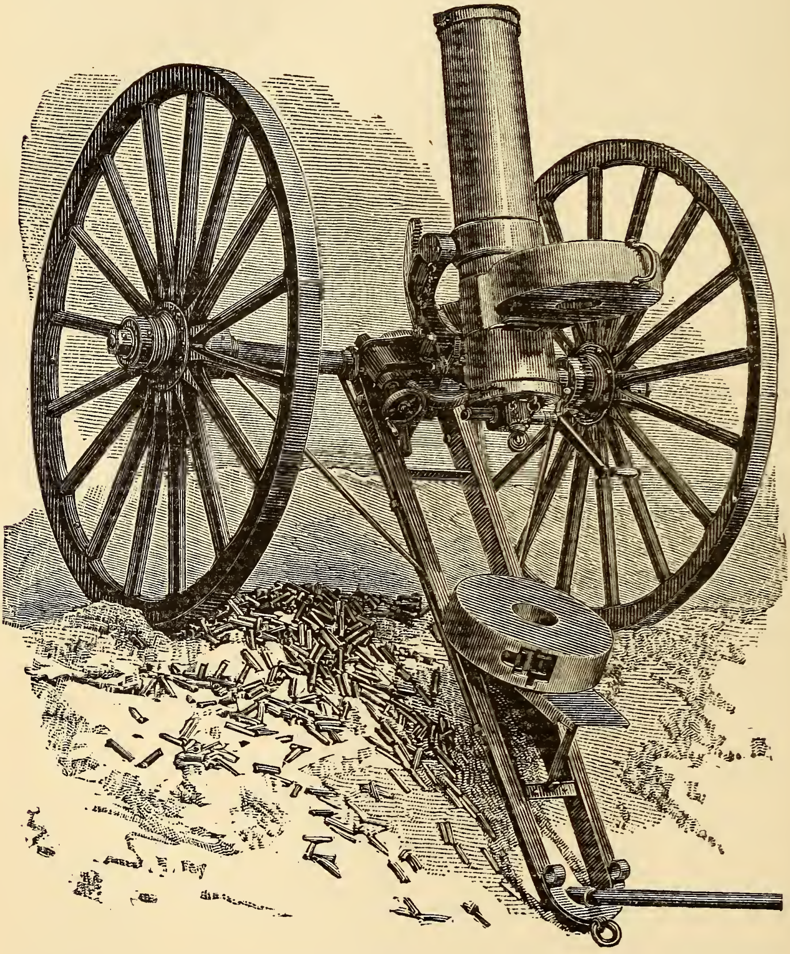
History furnishes abundant evidence that it is to the improvement of arms that nations have owed their successes in war.

The First Napoleon was enabled to conquer most of the nations of Europe by the use of improved guns.

The Prussian army, in like manner, was enabled to defeat the Austrian forces by the use of breech-loading "needle-guns."

It behooves all nations to furnish their soldiers with the best arms that can be procured, and they should be taught their use in times of peace.

Intelligent men, who have carefully watched and noticed the march of improvement, and the steady development of new ideas, will perceive and acknowledge that the day is not far distant when machine-guns will be extensively employed in warfare; and the nation which is best supplied with them, and which best understands their tactical use, will best preserve the lives of its soldiers, and be in the best condition to make favorable treaties, and to preserve the integrity of its own dominions.



The above illustration represents the Gatling gun, with its improved feed, in position to deliver high-angle or mortar fire.

DISCUSSION.

THE CHAIRMAN.—This most interesting subject is now open for discussion, and members of the Institute and others are invited to present to the meeting their views upon the points suggested by the lecturer. Officers of the army present are cordially requested to take part in the discussion. Attention is especially invited to the somewhat novel feature (as applied to machine-guns) of *high-angle* fire.

Without presuming to add greatly to the interesting lecture of the distinguished inventor, I would beg to note that he has not mentioned all the good points apparent in the present development of the Gatling system; and he has modestly abstained from special reference to its adaptability to naval uses.

A statement of the principles that demanded the changes resulting in the present improved feed would have been much more interesting coming from the inventor himself, but I may perhaps be pardoned in making a hasty reference to them. This I shall do in view of their importance, and also in view of the logical manner in which certain grave defects in the system have probably been definitely eliminated.

It is clear that a machine-gun is almost worthless if not reliable; if not ready at all times for instant use, if ever unready. In an action on shore, a machine-gun that has *jammed*, as the expression goes, is a captured gun, if unsupported by others; the enemy well knows that if he does not charge he cannot take it, as its sustained fire is irresistible. Afloat, certainty of action at a given moment will be, if possible, even more important than on shore, as the use of a small-arm calibre piece will be limited to the cases of emergency of a close action between ships, to offensive and defensive auxiliary employment in ramming, and to defence against a torpedo attack by boats. Failure at such times might be disastrous.

The original feed, as you all probably remember, depended upon gravity alone for its action. The cartridges were *dropped* into a hopper, in the earliest model, falling undirected through a considerable interval. This first feed was a single vertical column of cartridges, similar to the tin case used until within a few months. It was found to be defective, in that accidental stoppages occurred, and that it contained too small an amount of ammunition to sustain a fire for any length of time. An Austrian officer suggested the drum feed (so called from its shape), which carried a number of columns of cartridges, each of which was in turn brought opposite the hopper, the whole drum being turned either by the revolving carrier or by hand. This feed corrected the defect of insufficient quantity; but the action, as before, depending on gravity, there were as frequent stoppages as in the earlier feed, and in order to relieve the gun the heavy drum had to be first removed.

The feed was again changed to a single column of cartridges, placed over the axis of the piece, and as near the bottom of the carrier as possible, in order that the fall of the cartridge might be reduced to a minimum. The perform-

ance of the gun was improved, but the old difficulty was still present. There was at any moment a liability to jam, which destroyed confidence in the gun. It might fail at a vital instant; and, as usually occurs, it probably would so fail.

The problem of overcoming this difficulty was by no means a simple one, and some of the best inventive talent of all lands was concentrated upon it. Nobel, Gorloff and Baranovsky in Russia, Hotchkiss and Broadwell, to say nothing of a score of clever mechanical minds in this country (among whom should be named Bruce of the Springfield Arsenal), have all attempted a solution.

The desideratum was: A magazine (susceptible of being quickly charged, and containing such a number of cartridges that while the weight loaded would not be too great for ready handling, it would still be sufficient for an effective salvo) which should possess such mechanical features that, while grasping each cartridge firmly to prevent movement in any but a desired direction, the cartridge would be guided along a given path, ending at the carrier, preserving its parallelism to the latter throughout the journey. Thus a *positive* action, as it is termed technically, would be gained, *in spite of gravity*, *if necessary*.

After years of practical experience and study, the present feed was proposed by Mr. George Accles, the firing expert of the Gatling Company. It has withstood the tests of many official trials in this country and abroad, and has, it would appear, corrected the most serious defect in the Gatling system, thereby, in all probability, quadrupling its value. The feed is simply a wheel, actuated by the revolving carrier, carrying the charge of (100) cartridges around in a spiral groove in the enclosing cylinder ends; the groove holds heads and points against movement in any direction but its own, and ends as a tangent to the revolving carrier, where the cartridges are successively, and without possibility of derangement, deposited for the action of the plunger-locks.

The method of filling these magazines (a feature nearly as important as the rapid delivery itself, since, the supply of prepared ammunition exhausted, the gun becomes useless) is ingenious, but is a natural consequence of their own mode of action. The test of feeding up against gravity with the feed under the gun, referred to by the lecturer, suggested this feature to a clever mechanic at Colt's (Mr. Goodall). It was to utilize the revolving feature of the gun in order to feed the feed. A crank turns a toothed wheel, which in turn revolves the feed-wheel in a direction reverse to that in delivery upon the gun, the cartridges being stripped into a flange-way grooving above, from the usual packing cases. In this manner there is given a rapidity in filling cases about equal to the delivery of fire of most of the rival systems of machine-guns, and, with a moderate supply of filled cases to begin with, the fire may be rendered continuous for the limited period of naval action emergencies, or for the duration of the critical moment of an engagement on shore.

I do not think the office of machine-guns of the calibre of the Gatling extends farther than this. Artillery of much greater power in range and accuracy will always hold its place in the *feeling* stage of an engagement, and in giving the hard knocks. The importance of machine-guns for this special purpose, however, is hardly contestable, even though the failures of the French with an imperfect weapon prejudiced the military world for a time against them.

It seems, too, in considering their employment on board ship, where the question of transportation of ammunition is somewhat secondary, that the effectiveness of machine-guns will increase with the number of shots per minute of delivery of fire. If within range, the greater the delivery, the more demoralizing will be the effect upon an enemy, whether he be charging, standing his ground, or retreating. In this the Gatling system stands quite alone. Its delivery is undeniably greater than that of its rivals.

The question also frequently arises as to the relative merits of the volley and the continuous fire. With our usually unsteady platform, I think most naval men will agree that the chances of damaging the enemy are greater with the continuous fire. The delivery should, however, in my opinion, be made in salvos of thirty shots each, or three turns of the crank, if the piece be used afloat, as the jet of balls would be greatly dispersed with a longer effort.

A very serious feature of machine-gun fire is the production of smoke, which is unavoidable with rapid delivery; frequently three turns are all that can be made before the target is obscured; therefore, captains should strive for the weather-gage.

Gun-servants should be carefully instructed in the proper method of delivering Gatling fire. The crankman soon finds with practice that there is a position where the least output of work on his part will accomplish the object; and it is fortunate that this result of least labor corresponds to the best performance of the gun.

The leverman or pointer should be taught the principles of wing-shooting, as here he not only has a moving enemy, but is unstable himself, and he delivers a stream of projectiles of which only a portion may be effective.

Although the inventor of the Gatling system feels that the present gun is nearly a finality in development, it seems as if we were likely, in the not very distant future, to hear of progress, if not in mechanical features or rapidity in delivery, at least in ballistics. Machine-guns are now shielded with steel aprons, which, like all else in the direction of armor, must be pierced by the gun. It is not improbable that we shall hear ere long of *high-power* musket calibre machine-guns, using charges equal in weight to one half that of the projectile, and steel or steel-cased bullets. I think we should hear of such guns now.

REAR-ADMIRAL C. R. P. RODGERS.—It seems to me, Mr. Chairman, that a subject as interesting as this is should be fully discussed at a meeting where so many, both of the Army and Navy, high in authority in matters relating to ordnance, are present.

To us who began long ago the profession of arms upon the sea, when nothing could be brought into action effectively except the heavy guns with which our ships were armed, it seems immensely important, now that we have arms of precision, that machine-guns should be brought prominently forward in naval actions that are to take place hereafter.

I happened to serve not very long ago in the Pacific, where, between certain ironclads, Peruvian and Chilian, and between unarmored ships and ironclads,

several engagements that attracted the attention of the world took place. No one cognizant of the facts could doubt for a moment the immense advantage gained by the Chilians in filling their tops with riflemen armed with breech-loading guns. In these encounters, as the ships approached each other, it became impossible, on the uncovered decks, for men to stand to their guns. They were driven time and again to shelter, and those of us who observed the engagements could but remark how greatly exposed those gunners were, and how terrific was the fire to which they were subjected.

In the English and French ships of war, and our own, then in the Pacific, the men at their guns were much exposed to this fire from an enemy's tops. This was especially the case in the smaller French ships, whose pivot-guns were unusually high. The Shannon, a superb English ironclad, carried most of her battery exposed to this fire; and with machine-guns and well-trained riflemen in an enemy's tops, the gunners of the Shannon could have stood to their guns only with great loss of life and a great strain upon the steadiness of their aim.

I had no thought of taking part in this discussion, but the very interesting and valuable statement of our chairman was followed by a long silence, and I have spoken simply to break the ice, and to induce the distinguished ordnance officers now present, to favor us with their views.

Brigadier-General S. V. Benét, U. S. A.—I certainly shall not attempt to add anything to what has been said by my old friend, Dr. Gatling, in his lecture, nor to what has been so well and appropriately said by the Chairman of this meeting. The fact is I am wholly in accord with everything that has been stated on this subject, and I will therefore only give you a few historical recollections. I believe I was the first officer of our services that had any connection with the Gatling gun. The year of the termination of the war, 1865, I knew nothing of this gun and had never seen it. Dr. Gatling, its now distinguished inventor, came to the Frankford Arsenal, where I was then in command, with the Gatling gun, which I was instructed by the Chief of Ordnance to inspect and improve if possible. I remember that it was a very crude affair, for I recollect particularly that the Doctor told me he had first got a cartridge and then built the gun around it, and it seemed to be so. I can say of him also that he had but little idea of the science of gunnery at that time, and I attempted during the several months that he remained with me to teach him the little that I knew. I am very happy to say that the pupil has far outrun his teacher. Very soon after my attention was called to the gun I found that there was one thing which was absolutely necessary to do to insure its success, and that was to make it a central-fire gun. The gun was of one-inch calibre, adapted to that famous cartridge around which he had built the gun. The cartridge had a folded head with rim-fire. It had in its rim three grains of percussion powder, and every time it was fired there was danger of injury to the cartridge, if not of destruction to the gun. This was about the infancy of the manufacture of metallic cartridges in this country. As you all know, metallic cartridges are at the best very troublesome things to make. During the war the rim-fire cartridges

were principally used, and especially with the Spencer guns. The idea of a centre-fire cartridge had been broached and experimented with, and I remember telling Dr. Gatling that the success of his gun depended very largely on his changing it to a centre-fire. He demurred, and we had quite a number of discussions upon the subject; but, finally, I was able to convince him. With many misgivings he decided that he would attempt to make the change, and certainly the result was most creditable to his mechanical and inventive faculty. Within forty-eight hours he brought me a drawing of a new centre-fire lock, and I presume that the principle involved in that lock, made nearly twenty years ago, will be found in the present perfected gun. After worrying over the subject for several months and doing the best I could with it, I finally recommended to the Chief of Ordnance that the gun should be sent to Fortress Monroe, to be examined and reported upon by disinterested parties. The result was that the report was so favorable that Secretary Stanton at once gave an order for the purchase of a hundred of these guns, fifty of which were to be of one-inch calibre and the other fifty of half-inch calibre. That was the first boost that the Gatling gun received. Since that time I have been a strong advocate of machine-guns, and I have used whatever influence I have possessed in getting appropriations for their construction and in having them issued to the army. Through the influence of Colonel Williston of the 2d Artillery, who has probably more practical knowledge in the use of the gun than any other man in the army, the interest felt in machine-guns has been largely increased. Upon my recommendation, General Sherman had Williston's battery, which is one of the ten in the Artillery service, made into a battery of machine-guns, and I believe at my suggestion that General Sherman had that battery sent to the School of Application at Fort Leavenworth, in order to be able to prove by practical tests whether the machine-gun is not a proper weapon to be used in connection with infantry and cavalry in active service.

I do not know that I have anything further to say, but I am very sure that Dr. Gatling is the father of machine-guns. I believe the use of the Gatling gun will become a permanent and prominent feature in our military system and an important factor in future wars. A large portion of the credit for the introduction of such arms is undoubtedly due to my old friend, Dr. Gatling.

COMMANDER W. S. SCHLEY.—In regard to the high-angle fire suggestion, an idea presents itself to my mind with regard to the inaccuracy of such a system, and the impracticability and difficulty of ascertaining the range that attends its use.

If we introduce an explosive shell, the fire of a shower of projectiles will accomplish the results sought. The conditions under which high-angle fire would fail appear to me to be when no definite range could be determined. If explosive shell were used, the piece would be fired certainly with much better effect. So far as high-angle fire is concerned it is not a matter of much importance. On board ship we generally elevate the piece into tops and fire at low angles down upon decks; consequently, the rifle-bullet would answer our purpose; but if the Gatling is to be used for general purposes in naval

warfare, it would seem to me to be necessary to adopt explosive shells similar in weight and penetrative power to those used in Nordenfeldt or Hotchkiss guns. At present the Gatling has only a special use—that connected with the shore operations of naval forces; but, I think, if it is to maintain its place in our armaments, it must have its calibre increased so as to give it effective power against torpedo boats as well as against men simply. I merely suggest these points in the hope of drawing out further discussion on these interesting questions.

Doctor R. J. Gatling.—In England they have "range-finders" and other means by which distances can be determined with greater accuracy, I think, than can be done by the explosion of shells fired from field-guns. Be that as it may, when men become entrenched, there will be time to ascertain how far the enemy is from you. You could get up near enough in the night to place your Gatling guns in pits or under cover, and then give the guns proper elevation by the use of a quadrant, so as to have the bullets discharged fall on men behind the entrenchments. The bullets so discharged descend nearly perpendicularly, and strike the ground with a force sufficient to penetrate two or three inches of timber. In this way men can be killed behind entrenchments—thus making such positions untenable.

These are points that I am glad have been brought forward in this discussion, as their consideration will be useful.

I have witnessed a great deal of shell firing from field-guns, both in this country and in Europe, and in my opinion it is difficult to determine accurately the distance of an object by such firing. To the eye, the shells seem to burst just in front of a target or near the object, when, in truth, they burst far short of the target or object fired at. I have seen field-guns fired at targets at one thousand yards range, and the shells seemed to explode in front of the target, and I have imagined that the target was riddled with missiles; but when the target was examined, a few hits only were noted. In such instances the shells had exploded before reaching the proper point in front of the target. I have witnessed some trials in target practice with field-guns, in competitive trials with the Gatling gun, where the number of hits of the former were so few as to be unworthy of note.

A competitive trial took place at Shoeburyness, England, between 9-pounder and 12-pounder English field-guns, and 1-inch, 0.65- and 0.42-inch calibre Gatling guns, Colonel Wray (now General) conducting the trials. Targets placed at various distances from the guns, as far as 2070 yards range, were fired at, and although the Gatling guns used on that occasion were not nearly so perfect and effective as the improved Gatlings now made, they hit the targets oftener at all ranges than the field-guns, which greatly astonished the members of the committee. General Wray, in his report of these trials, states that a Gatling gun is equal to three field-guns in effective killing power, up to sixteen hundred yards. And he further says, one battery of Gatling guns will take up only about one-fourth of the road space required for a battery of 9-pounder field-guns.

I wish to say, Mr. President, a few words about my friend, General Benét. He is very kind in his remarks, and I am glad to see that his memory is so clear as to our experiences at the Frankford Arsenal. I was worrying over the rim-fire cartridge. The trouble was that the heads of such cartridges were liable to burst and come off when fired, and I had no device that would extract the balance of the shells remaining in the chamber of the barrels. The General put me on the right track. "I would surely," said he, "change the cartridge to a centre-fire," *and he insisted upon it.* To make such change would involve some time and expense, and I was in a great hurry to get the gun into practical shape and general use, but he overcame every argument that I could bring forward and insisted on his idea of centre-fire. That centre-fire cartridge belongs to him, and was the first one made. He is justly entitled to the credit of his suggestion, and the perfect working of the gun to-day arises in a great degree from the adoption of the centre-fire and the metallic cartridge. It is with pleasure I give him the credit due him. I thank the General for his remarks, as they will greatly aid in preserving the history of the gun and cartridge.

The Gatling gun is the original arm of its class, and whatever merit there is in it belongs to the United States.

It is with pleasure I state that our own government has recognized the importance of this gun, and has given it a place in the field, in its forts, and on its ships. But it is stating only the truth when I say that the leading foreign governments have recognized the true worth of this gun, and that they are to-day better armed with it than our own government.

REAR-ADMIRAL C. R. P. RODGERS.—I would like to ask a question as to the penetrating power of the Gatling gun when used in this way against steel-clad torpedo boats.

THE CHAIRMAN.—Torpedo boats, as they are built at present with steel-plates, cannot be penetrated by the fire of the Gatling gun. They can be penetrated by the projectiles of machine-guns of a larger calibre.

COMMANDER W. S. SCHLEY.—In the discussion of this matter of machine-guns, and their general introduction into the service of various nations, the object in view has been to obtain a gun that would be effectual as a torpedo-arrester; it therefore seems to me that the Gatling gun, if it is to be of general use to us, should be adapted not only for infantry operations on shore, but also for naval operations, such, for instance, as preventing the placing of torpedoes. If it fails therefore to penetrate, it must of necessity give way to guns that will penetrate. The Hotchkiss, for example, and the Nordenfeldt, have the penetrating power, and they make use of it most effectually. At the battle of Alexandria it was a noticeable feature of the battle that the machine-guns, such as the Gatling, were not within range. No bullets from these guns were found in the two days' fight at that place, whereas balls fired by the Nordenfeldt guns were picked up on the beach. I believe that some of the prisoners of the English stated in a conversation with some of the English officers that their defeat

was entirely due to the screeching of the shells over their heads. If the Gatling guns that were used in the engagement had been actively used, as it appears they were, and discharged at the rate of 1000 a minute, it seems to me very strange that some balls were not found on the battle-field, if the guns accomplished the purpose intended, as did other guns in use at the time.

Doctor R. J. Gatling.—I will say in reply to the remarks just made, that my lecture would have been too long, had I taken up and discussed the merits of both the larger and smaller size calibre guns. I have therefore confined myself to the smaller calibre guns, which are light and effective, and well adapted for service in our navy, and for warfare of any kind.

Gatling guns can be, and are, made of large calibre. The 1-inch Gatling discharges half-pound balls, and has a range of over two and a half miles; but such guns are heavier than the musket calibre Gatlings, which are light and easily handled, and which have a range of 3500 yards.

In the bombardment of the forts at Alexandria recently, by the English, Commander Schley says he has seen it stated that, although Gatling guns of the small calibre were used by the ships of the attacking fleet, it was a curious fact that none of the balls from these guns could be found anywhere near the battle-field. To that statement I desire to say that I have had extended correspondence with gentlemen who were present when these naval engagements took place in front of Alexandria. I am informed that some persons assert that not only were no bullets found that had been fired from the Gatling guns, but that there were none of any kind to be found that were fired from the Nordenfeldt guns, which were also used in the action.

This is explained in this way: The bullets, fired from the ships at some distance, and coming down with considerable force, would naturally and necessarily sink in the earth. Especially would this most likely be so where the soil is sandy and loose, and where little pressure is required to sink anything in the ground. Then again, after the bombardment was over, before the English forces landed, the Egyptian soldiers and pillagers visited the battle-ground to see if anything of value was left, and it is not at all unlikely that, if any bullets had been in sight (which I think very improbable in view of the facts I have just stated) that these people would have collected them and carried them off as relics.

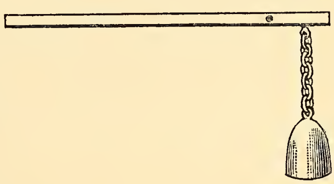
It is a fact, however, worthy of note that the Gatling gun is highly spoken of by the English officers who have used it, and who are in a position to know its merits as a weapon of war.

I do not think the English have adopted or purchased any Hotchkiss guns. My information is that the English on that occasion used no other machine-guns than the Gatling and the Nordenfeldt.

Lieutenant R. F. Nicholson.—I should like to ask the Chair if any experiments have been made in this country with the view of developing the power of small arms in the direction he referred to in his remarks.

THE CHAIRMAN.—A few experiments have been made at the Experimental Battery by direction of the Bureau of Ordnance, Navy Department, with a .50 calibre Remington rifle, old model, using considerably heavier charges than usual, in a longer chamber, and modifying the character of the powder grain. The results were quite satisfactory, a velocity of 1880 feet being obtained with 185 grains of powder and 450 of lead, without undue distress in recoil. The energy of a musket calibre bullet possessing such a high velocity was illustrated in the impact upon an iron plate one inch in thickness, against which the bullet was fired. Although the bullet was of lead, the indent was three-eighths of an inch in depth by one inch in diameter.

LIEUTENANT-COLONEL JAS. M. WHITTEMORE, U. S. A.—With the introduction of the positive feed to the Gatling machine-gun, two kinds of high-angle fire are made effective. These may be classed as direct and indirect: direct, when the gun is aimed at the object; indirect, when the bullets are fired up in the air, in order to hit the object in their fall. The direct fire should be used when practicable, as it is the more destructive and saves time in its death-dealing mission. To protect men on the spar-decks of ships-of-war from the deadly effect of the fire of machine-guns, the exposed parts ought to be bullet-proof, either permanently or temporarily. Iron shields, hinged at the sides of the deck to fold down upon it when not in use, might answer a good purpose. When required to shield the men they could be raised to an angle of about forty-five degrees and supported by struts; they would form a very good sloping protection from bullets; when hit by large projectiles they would stand a chance of being knocked down as well as knocked to pieces. They could be balanced at any angle by chains and weights attached near the hinge and running to the lower deck. When raised, they should be so arranged that if struck by heavy shot they would not be knocked down upon the deck, thereby possibly crushing men behind them. This could be done with bolsters. When folded down, they would assist in protecting the deck from indirect high-angle fire. These high-angle fires, made effective by the positive feed, increase the power of the gun as an important weapon for the suppression of riots. Mounted upon a movable platform on rollers, protected by shields, and pushed along from the rear, buildings and streets could be cleared with little exposure to the men manœuvring the gun. A platform could have two guns mounted upon it; one to clear the streets and the first stories of houses, the other to clear upper stories and roofs by direct and indirect high-angle fire.



THE CHAIRMAN.—In resuming the discussion, the Chair begs to note particularly the point raised by the Chief of Ordnance on the necessity for reliability in the ammunition for guns of the class in question.

No system of machine-guns can furnish even an acceptable performance with bad ammunition. In spite of the various plans for eliminating the disadvantages of burst cartridge shells, a cessation of the fire is the result of such an accident, with a delay more or less long, dependent generally upon the coolness of the operators. Many of the failures in official trials have been due solely to the ammunition. In this connection we have in this country great reason to congratulate ourselves upon the present high development in excellence of the U. S. cartridge as manufactured at the Frankford Arsenal.

The question of high-angle fire is extremely interesting, and it may develop even afloat, where its usefulness would at first seem to be limited, into a feature of considerable importance.

We can all recollect many cases during the Civil War, particularly in river service between high, overhanging banks, where high-angle fire would have been an effective factor. An opportunity for testing its value was also presented in the Corean expedition. Moreover, it will be useful at low angles in repelling an enemy close aboard.

With regard to its accuracy at high angles, there will doubtless be much to wish for. The projectiles at the great altitude reached where motion of translation and rotation nearly ceases are greatly affected by even a very light breeze, and except in calm weather a range-table would be of slight utility. A further disadvantage in correcting the range, as suggested in the remarks of Commander Schley, is found in the very slight disturbance of the surface of the water by the fall of musket calibre projectiles fired at high angles. There is, perhaps, no disturbance at all on land.

In conclusion, the Chair begs to tender the thanks of the meeting to the lecturer for his interesting essay, and also to the officers of the Army for their participation in the discussion.

PROFESSIONAL NOTES.

AIR-REFRIGERATING MACHINE.

Reprinted from a Report made to the Bureau of Steam Engineering by a Board composed of the following officers: Chief Engineer B. F. ISHERWOOD, *U. S. N.; Chief Engineer* THEODORE ZELLER, *U. S. N.; Chief Engineer* ROBERT DANBY, *U. S. N.* April 6, 1883.

The subject of this report is the air-refrigerating machine devised by S. B. Hunt, and submitted by him in November, 1879, to the Navy Department for examination of its capability to ventilate completely the entire interior of naval vessels with cool dry air, for the purpose of increasing the health and comfort of the *personnel* therein embarked, to enable fresh meat and vegetables to be carried for long periods, and to enhance the durability of the vessels, if constructed of wood.

Of the Board of Naval Officers appointed to make this examination, Chief Engineer Charles E. De Valin was a member. He devised and conducted the experiment hereinafter described, and took all the necessary data during its progress, with the intention of making it the subject of a special report to the Bureau, as such an experiment was not within the purview of the Board; but, his intention being frustrated by orders to sea, he gave his notes to the undersigned, who used their data in the present investigation, made the required calculations, and submit the results in the belief they will be found of permanent value. The subject is not only of considerable engineering interest, but is certain to frequently recur, and the undersigned do not know of any other experiment with an air-refrigerating machine in which complete and accurate data were taken.

The special object of the machine in question, and for which alone it was designed, is to furnish dry air of very low temperature, to be delivered into an air-tight chamber, constructed with non-heat-conducting floor, ceiling, and sides. A constant, but very slow current of the refrigerated air circulates through and out of this chamber by means of a small outlet pipe in the ceiling, fitted with a valve. The circulation is just sufficient to maintain the desired low temperature by the replacement of air that may become too much heated, by freshly refrigerated air. Of course, the quantity required of the latter, per unit of time, depends on the atmospheric temperature and on the more or less non-conductibility of the material of which the chamber is built. This chamber is used for the storage of fresh meat to be preserved for very long periods from putrefaction. Notably, this is an important employment of the system on board transoceanic steamers freighted with fresh meat for a market in foreign ports. The dryness of the refrigerated air is a very valuable factor in this connection, as air of a low temperature, if containing much moisture, is unsuited for the purpose, the meat becoming mildewed after short exposure in it. The proper temperature for the chamber is found to be a few degrees above the freezing point. It is not desirable to freeze the meat, but only to keep its temperature sufficiently low to prevent decomposition.

The machine on which the experiment was made is a permanent fixture in the large market at the Hudson river end of West Thirty-fourth street, New York

City, where the refrigerated chamber is successfully used for the storage of fresh meat or other articles of food requiring a low temperature of dry air for their preservation.

The refrigeration of the air is produced by a purely mechanical method, in conformity with the mechanical theory of heat; no chemicals are employed, and the atmospheric air is the only substance operated on. The air is first compressed in a cylinder to a convenient degree by a steam engine, and its heat of compression due to the work performed upon it, extracted by subjecting it in pipes exposing sufficient surface for the purpose to the external air, or to water, or to both, until its temperature falls to that of the atmosphere, the pressure being meanwhile maintained by the steam engine. Then the compressed air is admitted to a cylinder in which it acts expansively upon a piston and does work, the pressure of the expanding air being always equal to the resistance against which it acts, and for every 789¼ foot-pounds of work performed by the expanding air one Fahrenheit unit of its contained heat is extracted, this quantity of heat being transmuted into that quantity of work. Finally, the air thus refrigerated is delivered into the chamber where its low temperature and the dryness resulting from that lowness are to be utilized. Of course, instead of being exhausted into a relatively small chamber, the refrigerated air could be distributed by proper pipes and registers through the apartments of a vessel, which would thus undoubtedly be supplied with air of low temperature to any extent that the required space and weight could be allowed for the refrigerating machine, for the fuel needed for its steam engine, and for the distributing pipes.

The following is a description of the machine.

REFRIGERATING MACHINE.

The machine is composed, first, of a non-condensing, unjacketed, horizontal steam cylinder, in which power is developed in the usual way from steam supplied by a boiler. This cylinder has no expansion valve. The steam valve is the ordinary three-ported slide without lap, so that the steam is worked without expansion from the beginning to the end of the stroke of the piston. The power is graduated by an ordinary butterfly throttle-valve, placed in the steam pipe near the cylinder, and controlled by an ordinary governor. The steam valve has neither steam lead nor exhaust lead. The steam could not be used in a more wasteful and unskilful manner for the production of power. This, however, does not affect either the efficiency or the economy of the system, as nothing prevents the employment of an engine of the most improved type. The cylinder is 14 inches in diameter, with 12 inches stroke of piston. The piston is attached directly to a horizontal main shaft whose axis is at right angles to the axis of the cylinder, by means of the usual piston-rod, crosshead working between guides, and connecting-rod articulated to the crank-pin of a single crank.

Next, the steam power is employed to work duplicate air-compressing cylinders, both of which are horizontal and single-acting, with their axes in the same horizontal plane as the axis of the steam cylinder. The two air-compressing cylinders are in horizontal extension of each other, the pistons of both being keyed to the same piston-rod, so that these two single-acting cylinders are equivalent to one double-acting cylinder of the diameter and piston stroke of either. The steam cylinder and the compressing cylinders lie side by side, with but a narrow space between them. The pistons of the air-compressing cylinders are worked directly from the pin of a pair of cranks on the main shaft through a connecting-rod, crosshead between guides and piston-rod. The diameter of the air-compressing cylinders is 12 inches, and the stroke of their pistons is 9 inches. One end of these cylinders has no cover, but is left open to the atmosphere, while the other end is closed by a single disk-valve of

the same diameter as the cylinders, moving horizontally on a guide, opening outwards, and performing the functions of an air-delivery valve. At the centre of this disk-valve is another and very much smaller one, opening inwards, moving horizontally on a guide, and performing the functions of an air-receiving valve; through it the compressing cylinders are filled with air of atmospheric pressure, which, after being compressed to the maximum tension, is expelled through the delivery valve into a long pipe that connects the two compressing cylinders with the air-expanding cylinder to be hereafter described. The compressing cylinders have no clearance, and no passage between them and the seats of their valves. Their pistons advance to the extreme ends of their cylinders, whose delivery valves open before the pistons reach the termination of their stroke. During the experiment hereinafter described the air in the compressing cylinders received its maximum tension when the pistons of those cylinders had performed the 0.778 of their stroke; then the delivery valves opened, and the tension remained the same during the remaining 0.222 of the stroke of the pistons, the compressing pistons compressing the air in the cylinders throughout that 0.222 of their stroke, and throughout the pipe connecting the air-compressing cylinders with the air-expanding cylinder, which air was undergoing continuous decrease of bulk by external cooling from the opening of the air-delivery valve of the compressing cylinders to the opening of the air-receiving valve of the air-expanding cylinder, this continuous decrease of bulk being compensated by the corresponding continuous compression, so that the tension of the air remained nearly constant. This tension would have been constant but for the resistance of the inner surface of the connecting pipe, and of its bends to the movement of the air, which resistance caused the pressure to continuously decrease in the pipe from its compressing cylinder end to its expanding cylinder end, and, in addition to thus maintaining at nearly constant pressure the continuously decreasing bulk of air throughout the latter 0.222 of their stroke, and throughout the connecting pipe between the compressing and expanding cylinders, the compressing pistons drive the piston of the air-expanding cylinder through the portion of its stroke performed before the expansion valve on that cylinder closes; consequently, the power exerted by the piston of the air-expanding cylinder before its cut-off valve closes, though developed in that cylinder, is directly developed by the pistons of the air-compressing cylinders.

The compressing cylinders, with the exception of their ends, were water-jacketed, the water circulating through the jackets being obtained without cost of power from the Croton mains supplying New York City with potable water. The jacket space of each cylinder was 1⅛ inches wide and 14½ inches long. The top of the jacket of each cylinder was open to the air, and presented a level surface of water 15 inches wide and 14½ inches long, from which evaporation was continually taking place. These water-jackets were greatly insufficient to take up the heat of compression; the temperature of the water when entering them was 55 degrees Fahrenheit, and when leaving them 118 degrees. The initial temperature of the compressed air was 60 degrees Fahrenheit, and its temperature when leaving the compressing cylinders was 280 degrees Fahrenheit.

The compressing cylinders being situated close beside the steam cylinder, and taking in their air through a vertical pipe of 3½ inches internal diameter, whose open top was 4 feet 4 inches above those cylinders, received air heated by the radiation from the steam cylinder and its steam pipe, and from the open water-surface of the jackets, so that it was heated ($60°—55°=$) 5 degrees above the general temperature of the air near the floor of the room containing the machine. The temperature of the atmosphere outside the building was about 40 degrees Fahrenheit.

The pipe connecting the two air-compressing cylinders with the air-expanding cylinder was of wrought iron, and had many bends or returns in order that it might be compactly arranged. In addition to its use for conveying the com-

pressed air from the former to the latter, its surface was employed to reduce the temperature of that air from the 280 degrees Fahrenheit which it had on entering the pipe to the 56 degrees which it had on leaving the pipe to enter the expanding cylinder; and this cooling was accomplished by exposing part of the surface of the pipe to the air outside of the room containing the machine, but inside the building containing that room, and the remaining part to water constantly flowing through a tank placed on the floor of the room and supplied from the Croton mains, with a temperature of 55 degrees Fahrenheit, which was maintained in the tank.

The pipe from the air-compressing cylinders to the tank had, for the length of 22 feet, an outside diameter of 1⅞ inches, and an inside diameter of 1.69 inches, and, for the remaining length of 270 feet, an outside diameter of 2⅞ inches and an inside diameter of 2.65 inches. The aggregate outside surface of this pipe was 214.02150 square feet, and its aggregate inside surface was 197.05162 square feet. The pipe immersed in the tank (in direct continuation of the preceding, the two forming one pipe) was 156 feet long, 1½ inches in outside diameter and 1.33 inches in inside diameter, exposing to the water an outside surface of 61.26120 square feet, and an inside surface of 54.31826 square feet. The pipe from the tank to the air-expanding cylinder (in direct continuation of the preceding and forming with them one pipe) was 20 feet long, 1⅞ inches in outside diameter and 1.69 inches in inside diameter, exposing to the air of the lower portion of the room containing the machine an outside surface of 9.81750 square feet, and an inside surface of 8.84884 square feet.

All these pipes were continuous and had their interiors in common. They were distributed in lengths returned upon each other for economy of space, like the pipes of ordinary steam-heaters. From the compressing cylinders a length of pipe rose vertically to a convenient height; thence the remaining pipe was nearly horizontal, being arranged with a slight and uniform inclination to the expanding cylinder, in order to drain whatever water might be deposited from the compressed air as it cooled.

The pipe surface, measured on the outside, exposed first to the air, was 214.02150 square feet, and measured on the inside was 197.05162 square feet, and that air had the temperature of 45 degrees Fahrenheit. Then a surface of 61.26120 square feet, measured on the outside of the pipe, and of 54.31826 square feet, measured on the inside, was immersed in the water of the tank, which water entered the tank with the temperature of 50.6 degrees Fahrenheit, and left it with the temperature of 55.2 degrees. Finally, the remaining 9.81750 square feet of pipe surface, measured on the outside, and 8.84884 square feet, measured on the inside, were exposed to air of 55 degrees Fahrenheit temperature in the lower portion of the room containing the machine.

The lowest depression of the pipe was just at its entrance into the expanding cylinder, and at that point a water-trap was placed, which delivered the water of deposition from the pipe as fast as it accumulated, and thereby prevented its entrance into the expanding cylinder. Had this water entered the expanding cylinder, the low temperature existing there would have congealed it into very hard ice, whose mechanical obstruction would have rendered the working of the machine impossible. This trap is an absolutely essential part of the air-refrigerating system, which could not be reduced to practice without it.

There is one horizontal double-acting air-expanding cylinder of 5¼ inches diameter, with 9 inches stroke of piston. Its axis is in the same horizontal plane as the axes of the steam cylinder and compressing cylinders, and it lies on the outer side of the compressing cylinders, so that the latter are between it and the steam cylinder. The piston of the expanding cylinder is connected directly to the crank-pin of a single crank on the main shaft, through the usual piston-rod, crosshead between guides, and connecting-rod. The air-expanding cylinder is fitted at each end with two poppet valves worked by cams. One valve, adjustable at will, is for the admission of the compressed air from the pipe, and it closes when any desired fraction of the stroke of the piston has

been completed, thus acting as the expansion valve as well as the admission valve of the air. The other valve is for exhausting the air from the cylinder; it opens when the piston has completed the air stroke, and remains open during the exhaust stroke. The air in the cylinder had neither lead nor cushion. The area of the port at each end of the cylinder was 1 square inch.

The portion of the stroke of the piston of the air-expanding cylinder performed while the expansion valve was open was done by the pressure of the air-compressing pistons through the medium of the air in the connecting pipe; the air for this portion of the stroke was therefore used absolutely without expansion. For the remaining portion of the stroke the piston of the air-expanding cylinder was driven entirely by the expansion of the air admitted during the first portion of the stroke; and all the refrigeration below the general temperature of the air in the room containing the machine was produced after the closing of the expansion valve by this expansion of the air in its performance of work upon the main shaft. The air entered the expanding cylinder at the temperature of 56 degrees Fahrenheit, and left it with the temperature of —57 degrees, making a total fall of temperature of 113 degrees Fahrenheit. All the power developed in the air-expanding cylinder was expended on the compression of air in the two air-compressing cylinders.

The steam cylinder, the two air-compressing cylinders, and the air-expanding cylinder are situated side by side on the same bed-plate, and had their axes in the same horizontal plane. They were all connected directly to the same main shaft, which extended clear across one end of the bed-plate. The compressing cylinders were between the steam cylinder and the expanding cylinder, so that the whole formed a compact arrangement, occupying a space 10 feet 4 inches long, 6 feet 7 inches wide, and 4 feet 9 inches high.

The space occupied by the water-tank was additional to the above, and was 13 feet long, 21 inches wide, and 11 inches high. The water from this tank was carried to the water-jackets of the compressing cylinders, and thence discharged.

The space occupied in the air by the pipe connecting the compressing and expanding cylinders was still more additional.

The chamber to be refrigerated was constructed with double floor, ceiling and sides of pine boards, and the intervening space was filled with sawdust. This chamber should have no inleakages of air, no outleakages except through the proper delivery, and its floor, ceiling, and sides should be as little heat-conducting as possible. The capacity of the chamber was 11,419 cubic feet, equivalent to the capacity of a cube whose sides are 22.519 feet. The chamber had near its top a hole of ¾-inch diameter, through which the air delivered by the expanding cylinder escaped into the atmosphere. The pressure in the refrigerated chamber was slightly greater than that of the atmosphere, so that any leakages must have been outward. The barometer in the chamber stood at 30.240 inches, and outside the chamber at 30.106 inches.

The exhaust pipe from the expanding cylinder to the refrigerated chamber was 12½ feet long, and had the outside diameter of 4 inches. It was exposed to an air-temperature on its outside of 56 degrees Fahrenheit. It entered the chamber at the height of 7 feet 5 inches above the floor. The ¾-inch diameter hole by which the air left the chamber was 9 feet above the floor.

The following are the dimensions of the principal working parts of the refrigerating machine:

STEAM-CYLINDER.

Number of steam-cylinders	1
Diameter of steam-cylinder	14 inches.
Diameter of piston-rod	$1\frac{15}{16}$ inches.
Stroke of steam piston	12 inches.
Net area of piston, exclusive of rod	152.4644 square inches.
Space displacement of piston per stroke	1.058785 cubic foot.

Space in clearance and steam passage at one end of cylinder	0.118215 cubic foot.
Area of steam-cylinder port (10 inches by 0.6 inch)	6 square inches.
Diameter of exhaust pipe (outside)	3 inches.
Length of exhaust pipe	59 feet.
Number of right angles in exhaust pipe	5
Length of crank-shaft or main shaft	67 inches.
Diameter of crank-shaft journals	$3\frac{7}{8}$ inches.
Length of crank-pin journal	$3\frac{1}{2}$ inches.
Diameter of crank-pin journal	$2\frac{7}{8}$ inches.
Length of connecting-rod between centres	42 inches.
Diameter of connecting-rod at crosshead neck	$1\frac{5}{8}$ inches.
Diameter of connecting-rod at crank-pin neck	$2\frac{1}{8}$ inches.
Number of fly-wheels on main shaft (one on each side of compressing cylinders)	2
Outside diameter of fly-wheels	$47\frac{1}{4}$ inches.
Breadth of rim of fly-wheels	4 inches.
Depth of rim of fly-wheels	$4\frac{1}{8}$ inches.

AIR-COMPRESSING CYLINDERS.

Number of air-compressing cylinders (single-acting)	2
Diameter of air-compressing cylinders	12 inches.
Diameter of piston-rod (no rod at the side of piston used)	$2\frac{3}{8}$ inches.
Stroke of the pistons	9 inches.
Area of one compressing piston	113.0976 square inches.
Space displacement of one compressing piston per stroke	0.58905 cubic foot.
There is no clearance nor passage to valves.	
Number of connecting-rods	2
Length of connecting-rods between centres	$53\frac{7}{8}$ inches.
Diameter of connecting-rod at crosshead neck	$1\frac{5}{8}$ inches.
Diameter of connecting-rod at crank-pin neck	$2\frac{1}{4}$ inches.
Diameter of crank-pin journal	$2\frac{7}{8}$ inches.
Length of crank-pin journal	$3\frac{1}{2}$ inches.

AIR-EXPANDING CYLINDER.

Number of air-expanding cylinders (double-acting)	1
Diameter of air-expanding cylinder	$5\frac{1}{4}$ inches.
Diameter of piston-rod	$1\frac{1}{2}$ inches.
Stroke of piston of air-expanding cylinder	9 inches.
Net area of piston, exclusive of rod	20.76395 square inches.
Space displacement of piston per stroke	0.1081456 cubic foot.
Space in clearance and steam passage at one end of cylinder	0.cc60081 cubic foot.
Area of cylinder port	1 square inch.
Length of connecting-rod between centres	$45\frac{3}{8}$ inches.
Diameter of connecting-rod at crosshead neck	$1\frac{5}{8}$ inches.
Diameter of connecting-rod at crank-pin neck	$2\frac{1}{4}$ inches.
Diameter of crank-pin journal	$2\frac{7}{8}$ inches.
Length of crank-pin journal	$3\frac{1}{2}$ inches.

SPACE OCCUPIED.

Bulk of the entire refrigerating machine, with the exception of the space occupied by the pipe exposing 285 square feet of outside surface and connecting the air-compressing and the air-expanding cylinders, in its various convolutions to obtain from external air and water the necessary cooling for the air within	323.132 cubic feet.
Side of a cube having the capacity of 323.132 cubic ft.	6.862 feet.

PROPORTIONS.

Cubic feet of capacity of steam-cylinder per cubic foot of capacity of air-compressing cylinders	1.79744
Cubic feet of capacity of steam-cylinder per cubic foot of capacity of air-expanding cylinder	9.79037
Cubic feet of capacity of air-expanding cylinder per cubic foot of capacity of air-compressing cylinders	0.18359
Aggregate cubic feet of capacity in both steam-cylinder and air-expanding cylinder per cubic foot of capacity of air-compressing cylinders	1.98104

BOILER.

The steam cylinder was supplied from one boiler having horizontal flues in direct continuation of the furnaces with horizontal tubes returning above the flues and furnaces. There was no steam chimney or other means for superheating the steam; but there was over the centre of the boiler a cylindrical steam drum or reservoir, from the top of which the steam pipe proceeded to the steam cylinder. This pipe was 321 feet long, 3 inches in inside diameter, and had nine right-angled bends. The front portion of the boiler was rectangular in plan, with a semicircular top. The back portion was cylindrical and its upper half was a horizontal extension of the semicylindrical top of the front portion. The following are the principal dimensions and proportions of the boiler, namely:

Extreme length of boiler	13 feet.
Extreme breadth of front portion of boiler	7 feet 3 inches.
Extreme diameter of back portion of boiler	7 feet 3 inches.
Extreme height of boiler exclusive of steam-drum	9 feet.
Height of steam-drum above top of boiler	4 feet.
Diameter of steam-drum	3 feet 6 inches.
Number of furnaces	2.
Breadth of furnace	3 feet.
Length of grate bars	6 feet.
Total area of grate surface	36 square feet..
Number of flues (three from each furnace)	6.
Inside diameter of flues, four of $11\frac{1}{2}$ inches and two of 17 inches.	
Length of flues	4 feet.
Number of tubes (iron)	72.
Outside diameter of tubes	$3\frac{1}{2}$ inches.
Inside diameter of tubes	$3\frac{1}{4}$ inches.
Length of tubes	8 feet 6 inches.
Diameter of chimney	2 feet 4 inches.
Height of chimney above level of grate bars	47 feet 6 inches.
Area of heating surface in the flues	83.776 square feet.
Area of heating surface in the tubes, calculated for their inside circumference	520.730 square feet.
Area of all other heating surface	251.494 square feet.
Total area of heating surface	856.000 square feet.
Cross-area of the flues for draught	6.038 square feet.
Cross-area of the tubes for draught	4.148 square feet.
Cross-area of the chimney	4.276 square feet.
Square feet of heating surface per square foot of grate surface	23.778
Square feet of grate surface per square foot of cross-area of flues	5.962
Square feet of grate surface per square foot of cross-area of tubes	8.679
Square feet of grate surface per square foot of cross-area of chimney	8.419

The boiler and steam pipe were thoroughly protected from heat radiation by felt and lagging. The feed water was taken from the mains of the Croton Aqueduct, in which the pressure was so great that scarcely any expenditure of power was required to do the feeding.

THE EXPERIMENT.

With the refrigerating machine as described, an experiment was made on the 18th of November, 1879, of eight hours and fifty-five minutes, consecutively, duration. Indicators were placed permanently on the steam cylinder, on the air-compressing cylinders, and on the air-expanding cylinder, from each end of all which an indicator diagram was taken every half hour; eighteen complete sets of diagrams were thus taken during the experiments and equi-spaced over it. The results hereinafter given are the means of all these diagrams.

The variation in the steam pressure (controlled by a governor), and in the revolutions of the main shaft (equalized by two heavy fly-wheels), were so slight that the mean results from the diagrams may be taken to represent accurately the mean performance for the whole time.

The number of revolutions made by the main shaft was taken by a counter.

Compared thermometers were permanently hung so as to give the temperature of the air in the market building outside of the chamber containing the refrigerating machine, the general temperature of the air in that chamber, and the local temperature of the air entering the compressing cylinders. Two thermometers were permanently inserted in the pipe connecting the compressing and expanding cylinders, one being placed as close as possible to the air-compressing cylinders so as to give the temperature of the compressed air when leaving them, and the other being placed as close as possible to the air-expanding cylinder so as to give the temperature of the compressed air when entering it. Two other thermometers were permanently inserted in the exhaust pipe of the air-expanding cylinder, one as close to that cylinder as possible to give the temperature of the air leaving it, the other as close as possible to the refrigerated chamber to give the temperature of the air entering it. This exhaust pipe connects the air-expanding cylinder with the refrigerated chamber. A thermometer was placed in the refrigerated chamber 18 inches from the end of the exhaust pipe of the air-expanding cylinder, in order to obtain the temperature of the refrigerated air after it had spread that short distance into the chamber. Another thermometer was so hung as to give the general temperature of the air in the refrigerated chamber. And still another was hung to give the temperature of the air as it left this chamber. The temperature of the water from the Croton mains, used for feeding the boiler and supplying the cooling tank and water-jackets, was also given by permanently placed thermometers, which showed the temperatures of this water when entering and leaving the tank and when entering and leaving the jackets.

Compared barometers were placed in the chamber containing the refrigerating machine and in the chamber refrigerated, to show the difference of pressure in them.

Pressure gauges were permanently inserted into the boiler; into the steam pipe near the steam cylinder, but on the boiler side of the throttle-valve; into the pipe connecting the air-compressing and air-expanding cylinders at the point where the compressed air leaves the former, and at the point where the same air enters the latter.

All the water passing through the tank and through the water-jackets was measured. This quantity is the same for both tank and jackets, the water being led from the former through the latter. All the water discharged from the water-trap placed in the lowest point of the connecting pipe close to its entrance into the air-expanding cylinder, was measured. The temperature of this water, on emerging, was the same as that of the compressed air at the same place.

All of the above quantities were observed every half hour and entered in the columns of a tabular record. The means of these columns will be found below.

The coal consumed was Pennsylvania anthracite of good quality. It was carefully weighed, as was also its refuse in ash, clinker, and dust.

The following are the means of the entire performance, the quantities being arranged in groups for facility of reference :

STEAM-CYLINDER.

ENGINE.

Steam pressure in the boiler, in pounds per square inch above the atmosphere	60.
Steam pressure in the steam-pipe near the cylinder, on the boiler side of the throttle-valve, in pounds per square inch above the atmosphere	47.
Atmospheric pressure in the chamber containing the refrigerating machine in pounds per square inch	14.778
Temperature of the feed water, in degrees Fahrenheit	50.6
Temperature, in degrees Fahrenheit, of the air in the chamber containing the refrigerating machine	55.
Number of double strokes made per minute by the steam piston	143.875

NOTE.—The steam was not cut off by either independent expansion valve or by steam lap on the steam valve. The steam was neither cushioned nor released before the end of the stroke.

STEAM PRESSURES IN THE CYLINDER PER INDICATOR.

Steam pressure on the piston in pounds per square inch above zero, at the commencement of its stroke	60.
Steam pressure on the piston in pounds per square inch above zero, at the end of its stroke	53.
Mean back pressure against the piston in pounds per square inch above zero	25.770
Minimum back pressure against the piston in pounds per square inch above zero, at commencement of its stroke	16.780
Indicated pressure on the piston in pounds per square inch	28.912
Net pressure on the piston in pounds per square inch, applied to air compression	26.751
Total pressure on the piston in pounds per square inch	54.682

HORSES-POWER.

Indicated horses-power developed by the steam piston	38.4369
Net horses-power developed by the steam piston applied to air compression	35.5641
Total horses-power developed by the steam piston, calculated to zero	72.6966

RATE OF COMBUSTION.

Pounds of anthracite consumed per hour	297.0841
Pounds of combustible, or gasifiable portion of the anthracite, consumed per hour	247.5701
Per centum of the anthracite in refuse of ash, clinker, and dust	$16\frac{2}{3}$
Pounds of anthracite consumed per hour per square foot of grate surface	8.2523
Pounds of combustible consumed per hour per square foot of grate surface	6.8769
Pounds of anthracite consumed per hour per square foot of heating surface	0.3471
Pounds of combustible consumed per hour per square foot of heating surface	0.2892

ECONOMIC RESULTS.

Pounds of anthracite consumed per hour per indicated horse-power	7.7291
Pounds of anthracite consumed per hour per net horse-power......	8.3535
Pounds of anthracite consumed per hour per total horse-power......	4.0866
Pounds of combustible consumed per hour per indicated horse-power	6.4409
Pounds of combustible consumed per hour per net horse-power....	6.9612
Pounds of combustible consumed per hour per total horse-power...	3.4055

WEIGHT OF STEAM ACCOUNTED FOR PER HOUR IN THE CYLINDER.

Pounds weight of steam present per hour in the cylinder at the end of the stroke of its piston, calculated from the pressure there....	2546.7407
Pounds weight of steam of the pressure at the end of the stroke of the piston, theoretically required per hour for the total horses-power developed by the steam piston, including the steam in the clearances and steam passages of the cylinder, and supposing the steam to be used without expansion	2522.9467

AIR-COMPRESSING CYLINDERS.

TEMPERATURES.

Temperature, in degrees Fahrenheit, of the external atmosphere	40.
Temperature, in degrees Fahrenheit, of the air in the market building outside the room containing the refrigerating machine	45.
Temperature, in degrees Fahrenheit, of the air in the room containing the refrigerating machine	55.
Temperature, in degrees Fahrenheit, of the air when it enters the compressing cylinders	60.
Temperature, in degrees Fahrenheit, of the air when it leaves the compressing cylinders	280.
Number of Fahrenheit degrees of temperature imparted to the air in the compressing cylinders by compression	220.

PRESSURES.

Pressure of the atmosphere in pounds per square inch above zero	14.778
Mean pressure of the air in the compressing cylinders during the indraught stroke of their pistons, in pounds per square inch above zero, per indicator	14.778
Maximum pressure of the air in the compressing cylinders, in pounds per square inch above zero, per indicator	142.100
Pressure of the compressed air in the pipe immediately on leaving the compressing cylinders in pounds per square inch above zero, per gauge	140.515
Mean indicated pressure of the compressed air against the pistons of the compressing cylinders, in pounds per square inch above the atmosphere	55.060
Fraction of the stroke of the pistons of the compressing cylinders completed when the maximum air compression is obtained and the delivery valve opened	0.778
Mean pressure in pounds per square inch above the atmosphere, of the air in the compressing cylinders while being compressed during the 0.778 of the stroke of their pistons from the commencement, per indicator	34.440

HORSES-POWER.

Indicated horses-power exerted on the pistons of the compressing cylinders	40.7242
Horses-power exerted on the pistons of the compressing cylinders during the 0.778 of their stroke from the commencement, while the air was being compressed to the maximum pressure, per indicator	19.8180

UNITS OF HEAT ACCOUNTED FOR.

Pounds of water flowing per hour through the water-jackets of the compressing cylinders to cool their contained air	800.
Temperature, in degrees Fahrenheit, of the cooling water when it enters the water-jackets of the compressing cylinders	55.
Temperature, in degrees Fahrenheit, of the cooling water when it leaves the water-jackets of the compressing cylinders	118.
Number of Fahrenheit degrees imparted to the cooling water in the water-jackets of the compressing cylinders	63.
Number of Fahrenheit units of heat taken per hour out of the air in the compressing cylinders by the cooling water flowing through their water-jackets	50497.240
Pounds of natural air compressed per hour in the compressing cylinders	756.166
Number of Fahrenheit units of heat shown by thermometer to have been imparted per hour to the air compressed by the compressing cylinders, on leaving the latter	39626.123
Total number of Fahrenheit units of heat accounted for per hour, being the sum of the number in the cooling water from the jackets and in the air compressed by the compressing cylinders	90123.363
Number of Fahrenheit units of heat per hour equivalent to the horses-power expended in the compression of the air	102165.241
Number of Fahrenheit units of heat per hour dissipated by radiation from the surfaces of the compressing cylinders into the atmosphere	12041.878
Per centum of the Fahrenheit units of heat per hour equivalent to the horses-power expended in the compression of the air, dissipated by radiation from the surfaces of the compressing cylinders	10.001

AIR-EXPANDING CYLINDER.

TEMPERATURES.

Temperature, in degrees Fahrenheit, of the air entering the expanding cylinder	56.
Temperature, in degrees Fahrenheit, of the air leaving the expanding cylinder	—57.
Number of Fahrenheit degrees of temperature lost by the air in the expanding cylinder	113.

PRESSURES.

Pressure of the air in the pipe immediately before entering the air-expanding cylinder, in pounds per square inch above zero	136.78
Maximum air pressure on the piston of the air-expanding cylinder before the closing of the cut-off valve, in pounds per square inch above zero	93.00
Air pressure on the piston of the air-expanding cylinder at the closing of the cut-off valve, in pounds per square inch above zero,	87.00

Air pressure on the piston of the air-expanding cylinder at the end of its stroke, in pounds per square inch above zero	30.87
Mean back pressure against the piston of the air-expanding cylinder, in pounds per square inch above zero	16.83
Minimum back pressure against the piston of the air-expanding cylinder (at the commencement of its stroke) in pounds per square inch above zero	16.25
Indicated air pressure on the piston of the air-expanding cylinder, in pounds per square inch	39.67
Net air pressure on the piston of the air-expanding cylinder applied to air compression, in pounds per square inch	38.00
Total air pressure on the piston of the air-expanding cylinder, in pounds per square inch above zero	56.50
Fraction completed of the stroke of the piston of the air-expanding cylinder, when the cut-off valve closed	0.228
Number of times the air was expanded in the air-expanding cylinder,	3.72257
Mean pressure of the expanding air in the air-expanding cylinder after the closing of the cut-off valve, in pounds per square inch above zero	46.00

HORSES-POWER.

Indicated horses-power developed by the air-expanding cylinder	5.38685
Net horses-power developed by the air-expanding cylinder applied to air compression	5.16008
Total horses-power developed by the air-expanding cylinder	5.66549
Total horses-power developed in the air-expanding cylinder by the expanding steam after the closing of the cut-off valve	3.27304
Pounds of water collected per hour by the trap just in advance of the air-expanding cylinder	2.456

UNITS OF HEAT ACCOUNTED FOR.

Pounds of natural air discharged per hour from the air-expanding cylinder into the refrigerated chamber	368.806
Number of Fahrenheit units of heat per hour taken out of the air discharged from the air-expanding cylinder into the refrigerated chamber	10278.4019
Number of Fahrenheit units of heat per hour equivalent to the total horses-power developed in the air-expanding cylinder by the expanded air alone after the closing of the cut-off valve	8211.1109
Number of Fahrenheit units of heat per hour equivalent to the horses-power developed by the air during its expulsion of itself from the air-expanding cylinder into the refrigerated chamber after the opening of the exhaust valve	2067.2910

REFRIGERATED CHAMBER.

Pressure of the external atmosphere, in inches of mercury	30.1063
Pressure of the air in the refrigerated chamber, in inches of mercury,	30.2416
Temperature, in degrees Fahrenheit, of the air in the refrigerated chamber	39.

REMARKS.

For the calculations on air in the foregoing table, its specific heat is taken at 0.2382, which is the mean of the independent determinations made by Regnault and by Weidemann, the specific heat of an equal weight of water at the temperature of 32 degrees Fahrenheit being taken as unity.

The air, when drawn into the air-compressing cylinders, is supposed to contain a quantity of aqueous vapor equal to three-fourths of what it could contain at its temperature if saturated, and when discharged from the air-expanding cylinder it is supposed to contain one-third of the quantity of aqueous vapor it held when it was drawn into the air-compressing cylinders, the remaining two-thirds having been deposited as water in the pipe connecting the air-compressing and air-expanding cylinders, from which pipe this water was trapped out before the air entered the air-expanding cylinder. The weight of aqueous vapor contained in a cubic foot of natural air under the experimental conditions of temperature and pressure was taken from Regnault's hygrometric tables, and his weight of chemical air per cubic foot, that is, of air exclusive of aqueous vapor and carbonic acid gas, was modified in accordance with the assumed quantities of aqueous vapor with which it was mixed.

The coefficient of the expansion or contraction of air under constant pressure is taken to be 0.00204 of the air's bulk at the temperature of 32 degrees Fahrenheit for each added or subtracted Fahrenheit degree of temperature.

The Fahrenheit unit of heat is the quantity of heat required to raise the temperature of one pound of water from 32 to 33 degrees Fahrenheit under the standard atmospheric pressure.

The mechanical equivalent of one Fahrenheit unit of heat is taken to be 789¼ foot-pounds, and as one-horse power is 33,000 pounds raised one foot high per minute, the thermal equivalent of one-horse power is $\left(\frac{33,000}{789\frac{1}{4}}=\right)$ 41.811847 Fahrenheit units of heat, which number, multiplied by the number of horses-power developed, and by 60—the number of minutes in an hour—will give the number of Fahrenheit units of heat equivalent to the mechanical work performed by the horses-power during an hour.

The number of Fahrenheit units of heat in a given number of pounds of air between two Fahrenheit temperatures is found by multiplying the number of pounds of air by the number of degrees between the two temperatures and by 0.2382.

In calculating the number of Fahrenheit units of heat imparted to the cooling water supplied to the jackets of the air-compressing cylinders, the difference in the specific heat of the water at the entering and at the leaving temperature was included.

The total horses-power exerted by the steam cylinder is calculated for the mean pressure on the piston taken down to the zero line or line of no pressure, and this mean pressure is the sum of the mean indicated pressure and of the mean back pressure on the piston during its stroke. The total horses-power, therefore, expresses the entire mechanical work of the steam; for, overcoming the back pressure against the piston is as much mechanical work as overcoming any other resistance.

The indicated horses-power is that portion of the total horses-power which is employed in doing the commercial work required and in overcoming the frictions of the machine, the commercial work in the present case being the compression of air.

The net horses-power is what remains of the indicated horses-power after subtracting the horses-power absorbed by all the various frictions of the machine. This is the power which is employed wholly in compressing air—that is, in doing commercial work.

In the air-compressing cylinders and in the air-expanding cylinder, all the operations are above the atmospheric pressure, that pressure, in fact, representing for those cylinders the zero line or lowest limit of pressure, because the air compressed or expanded had already the atmospheric pressure before these operations were performed upon it. The indicated pressure is, of course, the mean pressure as given by the indicator diagram. For the air-compressing cylinders there is neither net pressure nor total pressure, as the atmospheric pressure is the back pressure, and as the indicated pressure is entirely exerted

in the compression of the air. For the air-expanding cylinder the total pressure is the indicated pressure plus the difference between the atmospheric pressure and the back pressure, this difference being caused by the too restricted opening and by the sinuous passage for the escape of the expanded air at the end of the stroke of the piston of the air-expanding cylinder. The net pressure is what remains of the indicated pressure after subtraction of the pressure required to work the air-expanding cylinder *per se.*

If the compressed air entered the air-expanding cylinder at its pressure in the valve-chest of that cylinder, and maintained this pressure until the cut-off valve closed, then the total horses-power developed by the expanding air alone in the air-expanding cylinder, to the performance of which work the refrigeration of the air is entirely due, would be calculated for the mean pressure of the expanding air after the closing of the cut-off valve, taken down to the atmospheric pressure line, as, overcoming the back pressure above that line is as much doing work as overcoming any other resistance. Of course, this mean pressure only acts for the portion of the stroke of the piston which remains after the closing of the cut-off valve. Again, if the compressed air in the air-expanding cylinder, instead of being expanded down to the atmospheric pressure, have, at the end of its expansion, a pressure greater than that of the atmosphere, it will, when discharged into the atmosphere, do work upon and heat the latter, experiencing itself a refrigeration equivalent to the work thus done; and this refrigeration will be additional to what is due to the work of expansion done upon the piston of the air-expanding cylinder.

This distribution of the power developed is absolutely necessary to an understanding of the processes of the air-refrigerating machine, and to a correct appreciation of its economic performance. Without such distribution there cannot be ascertained how much of the practically possible has been achieved, the causes of the limitations, and the reasons why the performance should be as it is experimentally found to be, thus reconciling the theoretical predictions with the results practically obtained.

During the process of compressing the air, heat will be generated in it equal to the thermal equivalent of the work of compression, and this heat, by expanding the air, will increase its resistance to compression; consequently, such heat should be extracted as fast as generated, so that the compressed air, when at the maximum compression desired in the compressing cylinder, should have only the atmospheric temperature. To wholly effect this, when the entire compression is done by a single operation in one compressing cylinder, may not be possible with the means at command, but the nearer the approximation the nearer perfection is the result. The means adopted in the experimental machine was to water-jacket the air-compressing cylinder, and, if the surface in the jacket could be made large enough relatively to the weight and temperature of the air within the cylinder, and to the quantity and temperature of the water practicable to be passed through the jacket per unit of time, then the desired cooling of the compressed air to the atmospheric temperature would be accomplished. The largest water-jacket surface will be obtained by giving the air-compressing cylinder the smallest diameter and the longest stroke of piston practicable. The air-compressing cylinder must of necessity be single acting, and its material might be bronze, which has a much greater heat-conducting capacity than cast iron. During the experiment, the water for the jackets was taken from the pipes supplying New York City with potable water under a pressure of over 50 pounds per square inch above the atmosphere, so that a very large quantity could be had without trouble and without expenditure of power by the machine; but in many locations, this water could only be obtained by a special expenditure of power for that purpose.

The area of water-jacket surface, relatively to a given weight of air to be compressed to a given tension in a given time, could be increased with a given stroke of piston, by distributing the space displacement of piston per stroke required into several air-compressing cylinders of proportionally reduced

diameter. The most effective method, however, of keeping the air in the compressing cylinder at the atmospheric temperature during the process of compression, is to conduct that process successively in several cylinders of decreasing capacities; the more numerous the succeeding cylinders, the more completely will the end be accomplished.

The first cylinder of the series must be of sufficient capacity in connection with the number of strokes made by its piston in a given time, to receive the desired amount of air of atmospheric pressure to be operated with in that time, but the compression is to be carried in this cylinder to only a fraction of the final compression; consequently, the heat generated in this cylinder will be only the relatively small quantity due to the smallness of the compression, and this small quantity can be taken out of the air as fast as produced by the water of the jacket.

From the first cylinder the partially compressed air having the atmospheric temperature is delivered into the second cylinder of the series, which has as much less capacity than the first as the final pressure in the first is greater than the initial pressure. In this second cylinder the air is still more compressed, but not to a greater tension than the water-jacket is capable of keeping at the atmospheric temperature during the compression.

From the second cylinder the air at the maximum tension received in it, but having the atmospheric temperature, is delivered into the third cylinder of the series, which has as much less capacity than the second as the final pressure in the second exceeds the initial pressure there; and in this third cylinder the air is still more compressed, but not to a tension exceeding that from which the water-jacket will extract the heat of compression as fast as generated; and so on, until the desired maximum pressure is reached.

This system is only a mechanical device for increasing the area in the water-jacket to the extent that will enable the water to absorb the heat of compression as rapidly as produced, so as to maintain the air in the air-compressing cylinders during the entire process of compression at the atmospheric temperature. Should the water-jackets, with a reasonable number of air-compressing cylinders, not prove sufficient to maintain the air undergoing compression, at the atmospheric temperature, that air, in its passage from one cylinder to the next, can be conducted through a coil of pipe immersed in a tank supplied with water, and the necessary cooling surface be thus obtained. Indeed, if the air, in its passage from one compressing cylinder to the next, be conducted through a sufficient length of pipe not immersed in water, but exposed to only the atmosphere, it is obvious that the temperature of the air undergoing compression may be kept during that process nearly down to the atmospheric temperature, and by this means an air-refrigerating machine might be successfully operated without water. The question is evidently simply one of surface of pipe.

In calculating the heat of compression for the experimental machine, the indicated horse-power given by diagrams taken from the air-compressing cylinders, is the measure of the work of compression; that is to say, the horse-power computed from the mean pressure above that of the atmosphere during the compression for the entire stroke of the pistons of the air-compressing cylinders.

That the resistance due to the heat of compression is wholly detrimental is evident from the consideration that the weight of atmospheric air taken in by the air-compressing cylinders during their indraught stroke of piston is a fixed quantity, and that—no air leakage being supposed—this same quantity at the same atmospheric temperature enters the air-expanding cylinder, the heat of compression having been taken out of the air after it left the compressing cylinders and before it entered the expanding cylinder, so that the air-expanding cylinder will develop precisely the same power, let there be no heat of compression in the compressing cylinders or much. The power developed by the expanding cylinder has a fixed proportion to that developed in the compressing

cylinders only when the temperature of the air is constant throughout. All the power developed in the air-compressing cylinders caused by the expansion of the air therein, due to the heat of compression, is entirely lost; hence the desirability of maintaining the air during compression at the atmospheric temperature, which allows the machine to be operated for a given quantity of refrigeration with the minimum of power so far as the compression of the air is concerned.

In the case of the experiments the air was received by the compressing cylinders at the pressure of 14.778 pounds per square inch above zero, and compressed to 142.100 pounds per square inch above zero, the compression being 9.615645 times. The mean total pressure against the pistons of the compressing cylinders was 69.838 pounds per square inch above zero, or 55.060 pounds per square inch above the atmosphere, and the heat of compression in the compressing cylinders was very great. Now, had that heat been extracted from the air as fast as generated, the mean total pressure against the pistons of the compressing cylinders would have been only 48.2738 pounds per square inch above zero, or 33.4958 pounds per square inch above the atmosphere, between the same limits of pressure, namely, 14.778 and 142.100 pounds per square inch above zero; and the horses-power expended in compressing the air would have been only 24.7746 instead of 40.7242, the experimental number; consequently, by reason of the heat of compression in the air within the compressing cylinder, there was required $\left(\frac{40.7242 - 24.7746 \times 100}{24.7746} =\right)$ 64.3788 per centum more power for effecting the same compression than if that heat had been taken out of the air as rapidly as generated, so as to preserve the temperature of the air undergoing compression constant throughout the entire process.

The temperature of the compressed air when leaving the compressing cylinders was 280 degrees Fahrenheit. This was the mean temperature for the whole mass of air delivered per stroke of the compressing pistons, but the maximum temperature within the compressing cylinders was considerably higher, and occurred at the point where compression reached its maximum, namely, when 0.778 of the stroke of the compressing pistons was accomplished and the delivery valve opened.

The air, with 60 degrees Fahrenheit of temperature and 14.778 pounds per square inch above zero of pressure, undergoing compression, had its temperature remained constant, would, when compressed into $(1.000 - 0.778 =)$ 0.222 of its original bulk, have had the pressure of $\left(\frac{14.778}{0.222} =\right)$ 66.568 pounds per square inch above zero, so that in order to raise its pressure under constant volume to 142.100 pounds per square inch above zero, which it experimentally had at the point where maximum compression was reached, its temperature must have been raised by the compression to 658.45 degrees Fahrenheit, because $\frac{142.100}{66.568} = 2.1347$, and, taking the pressure of the air at 32 degrees Fahrenheit as unity, its pressure at 60 degrees will be 1.06712, and at 658.45 degrees 2.277958, and $\frac{2.277958}{1.06712} = 2.1347$. Consequently, $(658.45 - 280.00 =)$ 378.45 Fahrenheit degrees of temperature were extracted from the compressed air in the compressing cylinders by the water of their jackets during the last 0.222 of the stroke of their pistons.

From the air-compressing cylinders, the compressed air is carried in a pipe to the air-expanding cylinder in which the refrigeration below the atmospheric temperature is to be effected, and, as it is absolutely necessary to the production of the maximum refrigeration that the compressed air should enter the air-expanding cylinder with a temperature not above that of the atmosphere, whatever residual heat it may contain above that temperature when leaving the air-compressed cylinders must be extracted by exposing it in a sufficient length of

pipe to the cooling influence of the atmosphere, or, still better, of water, or to that of both combined. If the whole of the heat imparted to the compressed air by the compression could be extracted by the water in the jackets of the air-compressing cylinders, there would, of course, be no necessity for any greater length of pipe than just enough to convey the compressed air to the air-expanding cylinder. The only purpose of the lengthened pipe exposed to the atmosphere and to water is to do what the water-jackets of the air-compressing cylinders failed to do for want of surface.

It is found that air taken from the atmosphere and compressed under constant temperature will not hold the same quantity of hygroscopic moisture which it held under only the atmospheric pressure, and the higher the pressure the greater will be the deposition of this moisture which must be removed before the compressed air is admitted to the air-expanding cylinder, for the double reason that the driest possible air is required, and that the ice which would be formed from this deposited water if admitted to the air-expanding cylinder, in which a very low temperature exists, would mechanically prevent the working of its valves and piston. The removal of this water of deposition is effected by a simple water-trap placed in the pipe just in advance of the valve-chest of the air-expanding cylinder, and so much of the hygroscopic water of the atmosphere is thus removed that no ice is found within the air-expanding cylinder whose mechanical action is not in the least impeded thereby. Of course, the pipe must be arranged to have a descent from the air-compressing to the air-expanding cylinder in order that the deposited water may flow to the trap by gravity. If the compressed air were cooled by the water in the jackets of the air-compressing cylinders to the atmospheric temperature, the deposition of the hygroscopic water would take place in them, and be forced out through a relief valve at the end of each compressing stroke of their pistons. But it might be found that more time is required for this deposition than is afforded in the cylinders, and that a certain length of pipe is needed for that purpose, irrespective of the extraction of any residual heat in the compressed air. This is a problem which can be solved by experience only.

From the pipe the compressed air, cooled to the atmospheric temperature and deprived of nearly all its hygrometric moisture, enters the air-expanding cylinder in which it undergoes refrigeration and develops power at the same time. This cylinder is furnished with induction, eduction, and cut-off valves, and a piston, precisely the same as the cylinder of a steam engine, and the air is used in it just as steam is used in a steam cylinder.

The piston of the air-expanding cylinder is connected by the usual piston-rod, crosshead, and connecting-rod with a crank on the same shaft that the steam piston is similarily connected with, so that this shaft is simultaneously operated by both the steam cylinder and the air-expanding cylinder, the work thus done, exclusive of what is absorbed by the frictions of the apparatus, *per se*, and of the load, being expended in the compression of the air within the air-compressing cylinders. The power, therefore, which compresses the air is the aggregate net power developed by the steam cylinder and by the air-expanding cylinder. Hence, the subtraction of the power exerted on the pistons of the air-compressing cylinders, as shown by the indicator diagram, from the sum of the indicated powers of the steam cylinder and air-expanding cylinder, leaves a remainder which is the power absorbed by the frictions of the entire machine, *per se*, and of the load. By the friction of the entire machine *per se* is meant the friction of all its moving parts due to their weight and to the tightness of the packings, from and inclusive of the piston of the steam cylinder to and inclusive of the connecting-rod of the air-expanding cylinder when the machine is unloaded, that is, when working at the experimental speed, but without compressing air. This friction is independent of and unaffected by the work of compressing the air, and the *pressure* on the pistons to overcome it is constant at all speeds of piston, the *power* being in the direct ratio of the piston speed. But, when the machine compresses air, there is brought into existence another

friction called the friction of the load, which is due to the additional pressure upon the moving parts caused by the additional resistance of the load. This latter friction has a fixed proportion to the load, and is independent of, and unaffected by, the former friction of the machine, *per se*. With the average lubrication of practice the friction of the load is 7½ per centum of the load.

The power shown by the indicator diagram for the portion 0.228 of the stroke of the piston of the air-expanding cylinder, comprised between the commencement of the stroke and the closing of the cut-off valve, though exerted *in* the air-expanding cylinder, was exerted *by* the pistons of the air-compressing cylinders, the communication being free from the latter to the former. After the closing of the cut-off valve the power exerted by the expansion of the air was exerted by the air-expanding cylinder, consequently, for overcoming the friction, *per se*, of that cylinder, there must only be subtracted from its indicated power what is required for moving the unloaded parts through the remaining $(1.000 - 0.228) = 0.772$ of the stroke of the piston, and for the friction of the load 7½ per centum of the remaining power exerted during the 0.772 of the stroke of the piston by the expanding steam above the back pressure against the piston. Hence, nearly all the frictions of the machine were overcome by the steam cylinder alone, the air-expanding cylinder contributing but little, as the expanding air in it exerted but little pressure above the back pressure in it.

The indicated horses-power expended in compressing the air was 40.7242. The aggregate indicated horses-power developed in the steam cylinder and in the expanding cylinder was $(38.4369 + 5.3868 =)$ 43.8237; consequently, the horses-power expended in overcoming all the frictions of the machine were $(43.8237 - 40.7242 =)$ 3.0995. Deducting from the aggregate indicated horses-power of 43.8237, developed by the machine, 1.0957 horses-power for overcoming the friction of the machine, *per se*, the remainder will be the horses-power applied to the crank-pins, namely, 42.728, of which 3.0995 horses-power is 7¼ per centum.

The pressure in the air-compressing cylinders from the opening of their delivery valves to the end of the stroke of their pistons was 142.100 pounds per square inch above zero, which fell to 140.515 pounds per square inch above zero as soon as the delivery valves were passed. The difference of the two pressures represents the force required to open the delivery valves and to deflect the current of the air from the direction of the piston course through several sinuosities into that of the pipe connecting the air-compressing cylinders with the air-expanding cylinder.

This pressure of 140.515 pounds, which was at one end of the pipe connecting the air-compressing cylinders with the air-expanding cylinder, fell, at the other end of the pipe, just before it entered the air-expanding cylinder, to 136.780 pounds per square inch above zero, the difference of 3.735 pounds per square inch representing the force required to overcome the surface resistance of the pipe to the air, and the resistance due to the numerous return bends in that pipe.

The adjustment of the admission valve to the air-expanding cylinder was so badly done that the maximum pressure was not attained in that cylinder until nearly the point of the stroke of its piston where the admission of the air was cut off. This unskillful adjustment of the valve, together with the too small area of the opening for admission, restricted the maximum pressure in the air-expanding cylinder to 93.000 pounds per square inch above zero, the loss of pressure between the valve-chest and the cylinder being 43.780 pounds per square inch, an excessive amount, most of which could have been avoided by proper mechanical arrangements and proportions, a difference of from 1½ to 2 pounds per square inch being easily obtainable. This great loss of pressure in the air-expanding cylinder materially lessened both the power recovered from that cylinder and the degree of refrigeration imparted to the air in it.

The point of cutting off in the air-expanding cylinder must be so regulated that the final pressure there will be just that of the back pressure against the

piston of that cylinder, care being taken by means of large openings and proper exhaust-valve adjustment, to make the back pressure as little above the atmospheric pressure as possible. Now, with a given quantity of air entering the air-expanding cylinder in a given time, and with the back pressure against the piston of that cylinder forming the lower limit of pressure, it is evident that the lower the initial pressure in the air-expanding cylinder the less will be the measure of expansion with which the air can be used; and the less the measure of expansion with which a given weight of air is used, the less will be the refrigeration of that air, for this refrigeration is in the direct ratio of the work done by the expanding air. Hence, the desirability of using the air in the air-expanding cylinder at the tension it received in the air-compressing cylinders less only the inevitable losses due to the transmission of that pressure from the pistons of the air-compressing cylinders to the piston of the air-expanding cylinder. Also, the higher the initial pressure and the greater the measure of expansion with which a given weight of air is used, the greater will be the power obtained from it. The function of the air-expanding cylinder is primarily to refrigerate the air used in it by the conversion into work of the heat of the air therein expanded calculated down to the atmospheric pressure; and, secondarily, to recover some of the power expended in air compression. The capacity of the air-expanding cylinder relatively to the capacity of the air-compressing cylinders should be so proportioned that the air being received by the former from the latter with as little loss of pressure as possible should be cut off at the earliest point which would make the final pressure after expansion just equal to the back pressure. These two pressures in the air-expanding cylinder, namely, the initial pressure upon, and the back pressure against, its piston, determine the measure of expansion with which the air can be used, as the expansion curve must pass through both.

There were discharged from the air-expanding cylinder at the end of the stroke of its piston only 368.806 pounds of air per hour, although the air-compressing cylinders had compressed 756.166 pounds of air per hour, the loss being 51.227 per centum of the weight received by the machine, leaving only 48.773 per centum of that weight delivered by it. This loss is due entirely to leakage of the highly compressed air out of the machine into the atmosphere and to its regurgitation past the pistons and valves.

Nothing is more difficult than making joints and packings sufficiently tight to hold highly compressed air, and the enormous velocity with which such air rushes into the atmosphere permits a great weight of it to escape through very insignificant openings. Practically, allowance must always be made for a loss of about one-half of the air compressed, and although this seems a large estimate, it will not be found too large for lengthened performance of the machine under the conditions of ordinary practice.

The number of Fahrenheit units of heat per hour taken out of the air discharged from the air-expanding cylinder was

$$(368.806 \times 117 \times 0.2382 =)\ 10278.4019,$$

which is equivalent to the work of expansion of 4.09708 horses-power. Now, the expanding steam alone in the air-expanding cylinder after the closing of the cut-off valve developed only 3.27304 horses-power, calculated down to the line of atmospheric pressure; consequently the complementary 0.82404 horses-power was supplied by the expansive working of the air discharged into the atmosphere at the end of the stroke of the piston. The pressure of the air at the end of the stroke of the piston was 16.092 pounds per square inch above the atmosphere, and, in its expansion down to the atmospheric pressure, must have done considerable work upon the atmosphere which it heated and itself underwent an equivalent refrigeration to the work thus done.

There were required to compress the air in the air-compressing cylinders 40.7242 horses-power, of which there were recovered for that work by the air-expanding cylinder 5.16008 horses-power; that is to say, of the 40.7242 horses-power expended in compressing air, only 5.16008 were contributed by the air-

expanding cylinder. The total horses-power, calculated down to the line of atmospheric pressure, developed in the air-expanding cylinder, was, indeed, 5.66549, the difference of 0.50541 horses-power being consumed in working the cylinder, *per se*, and in overcoming the back pressure against the piston above the atmospheric pressure.

Now, if the air had been compressed in the air-compressing cylinders at constant temperature and expanded in the air-expanding cylinder at the same, the latter would evidently have developed the same power as the former, supposing no loss of pressure between the cylinders and the expansion carried down to the atmospheric pressure. There has been shown that had the air been compressed at constant temperature, the horses-power developed in the air-compressing cylinders would have been only 24.7746, of which 51.227 per centum were lost by air leakage, reducing proportionally the 24.7746 horses-power to 12.08332, of which 5.66549 are accounted for by the air-expanding cylinder, leaving 6.41783 to cover the losses due to the want of expanding down to the atmospheric pressure; to the difference of pressure between that of the air in the air-compressing cylinders, namely, 142.100 pounds per square inch above zero, and that of the air in the air-expanding cylinder, namely, 93.000 pounds per square inch above zero at the beginning of the stroke of the piston, and 87.000 pounds at the closing of the cut-off valve, as well as the loss of pressure due to the refrigeration of the expanding air in the air-expanding cylinder, and the loss of air effect in the clearance and passage at the end of the air-expanding cylinder; likewise, the loss of the mechanical effect due to the weight of aqueous vapor condensed in the connecting pipe and trapped out.

The weight of air delivered per hour by the air-expanding cylinder being 368.806 pounds, and the refrigeration effected upon it being a fall in temperature of $(-57^\circ + 60^\circ =)$ 117 degrees Fahrenheit, the number of Fahrenheit units of heat destroyed per hour by the machine is $(368.806 \times 117 \times 0.2382 =)$ 10278.4019. That is to say, the quantity of heat destroyed per hour was sufficient to raise the temperature of 10278.4019 pounds of water at 32 degrees Fahrenheit one degree, or, as the latent heat of ice is 142.5 degrees Fahrenheit, the destruction of the above quantity of heat was sufficient to produce per hour from water at the temperature of 60 degrees Fahrenheit $\left(\frac{10278.4019}{60^\circ - 32^\circ + 142.5} = \right)$ 60.2839 pounds of ice at the temperature of 32 degrees Fahrenheit.

The quantity of air cooled per hour one degree Fahrenheit was $(368.806 \times 117 =)$ 43150.302 pounds, and as a pound of air at the temperature of 60 degrees Fahrenheit and under the standard atmospheric pressure occupies 13.44945 cubic feet, the refrigeration was equal to cooling per hour under that pressure $(368.806 \times 13.44945 =)$ 4960.2379 cubic feet of air one degree Fahrenheit, or $\left(\frac{4960.2379}{60^\circ - 32^\circ} = \right)$ 177.1513 cubic feet of air from the temperature of 60 degrees Fahrenheit to that of 32 degrees.

To accomplish this refrigeration there were expended in the actual condition of the machine 40.7242 net horses-power; that is to say, power exclusive of all frictions, whether of the machine, *per se*, or of the load. This is the power exerted on the pistons of the two air-compressing cylinders, as measured by the indicator, and for the mean pressure above the atmosphere. A net horse-power was therefore equal, under the actual conditions of the machine, to the lowering per hour of the temperature of $\left(\frac{10278.4019}{40.7242} = \right)$ 252.3905 pounds of water at 33 degrees Fahrenheit to 32 degrees; or, to the production per hour of $\left(\frac{60.2839}{40.7242} = \right)$ 1.4803 pounds of ice from water at the temperature of 60 degrees Fahrenheit; or, to the cooling per hour of $\left(\frac{43150.302}{40.7242} = \right)$ 1059.5740 pounds of air one degree Fahrenheit; or, to the cooling per hour of $\left(\frac{177.1513}{40.7242} = \right)$ 4.3500

cubic feet of air from the temperature of 60 degrees Fahrenheit to that of 32 degrees.

With a properly conditioned machine, the foregoing quantities of refrigeration could have been produced for about one-half of the above 40.7242 horses-power, and still allowed an air leakage of about one-half of the air compressed; indeed, had the heat of compression been taken out of the compressed air as fast as generated, the leakage would have been lessened; as the mobility of air is greater with greater temperatures.

The engineering skill with which the machine was designed was exceedingly faulty, and the fuel cost of the work done was proportionally and unnecessarily great. To operate the machine with the utmost economic advantage, the steam should be used in the steam cylinder according to the known methods producing the horse-power with the least expenditure of fuel, instead of which the steam was used in the most wasteful manner possible. It was not superheated; it was used absolutely without expansion; the cylinder was not steam-jacketed; the steam was admitted to the cylinder at the low initial pressure of 45 pounds per square inch above the atmosphere for a non-condensing engine, although the boiler pressure was 60 pounds per square inch above the atmosphere; the mean back pressure against the piston during its stroke was, owing to the very defective setting of the steam valve, 25.77 pounds per square inch above zero, the mean total pressure on the piston being only 54.682 pounds per square inch above zero, whereby nearly one-half of the steam was uselessly employed in overcoming the back pressure alone. Under these conditions the indicated horse-power cost 7.7291 pounds of anthracite per hour, which is about three times its cost with the most economical steam engine and the same economic vaporization by the boiler.

The air-expanding cylinder used the compressed air as extravagantly as the steam cylinder used the steam. Now, in order to obtain the most economical results from the expansion of the air, it should enter the expanding cylinder at the maximum pressure in the air-compressing cylinders, less only the inevitable loss of pressure due to its transfer, and the cut-off valve should close as soon as a sufficient quantity was admitted to produce a pressure at the end of the stroke of the piston equal to the back pressure against the piston, which by means of large exhaust openings, should be reduced to that of the atmosphere, the cylinder being made of the proper capacity, relatively to the weight of air supplied per stroke of piston by the air-compressing cylinders, to allow such a distribution. Of course the valves and piston should be as tight as practicable, and the air-expanding cylinder should be well covered with non-heat-conducting substances. The setting of the admission valve of this cylinder was so injudicious that the maximum pressure was not attained in it until after the piston had commenced its stroke, and when attained was far below what should have been. The air refrigeration is produced wholly by the expansion of the air when doing work. All the air that escapes use expansively upon the piston in doing work escapes refrigeration. The air should be expanded in doing this work as much as possible without falling below the atmospheric pressure, because if it did the power developed by it would be decreased and an economic loss sustained in that particular, and it should fall to that pressure in order to secure the greatest practicable expansion and consequent greatest practicable refrigeration. To obtain the greatest practicable degree of expansion it is evident that the initial pressure of the air must be the highest practicable, and its final pressure the lowest practicable. Now, the air pressure in the pipe connecting the air-compressing and the air-expanding cylinders was, just before entering the latter, 122.000 pounds per square inch above the atmosphere, while the maximum pressure in the air-expanding cylinder was only 78.222 pounds per square inch above the atmosphere. The pressure of the air in the air-expanding cylinder, at the end of the stroke of its piston, was 16.072 pounds per square inch above the atmosphere. These figures show how much less than the possible were the actual results, and they do not include the enormous unnecessary loss caused by not removing the heat of compression as fast as generated.

PRINCIPLES OF THE MACHINE.

If a given mass of air be taken at a given pressure, compressed to another, and then expanded back to the original pressure, its temperature remaining constant during these operations, the power developed or work done by its expansion will exactly equal the power exerted or work done in its compression, supposing the mechanism by means of which these operations are produced to have neither friction nor to leak air.

If there be friction and air leakage, the power developed by the expansion will be less than that exerted in the compression by the amount of the friction and leakage.

But if the air be kept at constant temperature during its compression only, receiving no heat during its expansion, then, during the expansion, its temperature will be lowered by the annihilation of so much of the heat contained in it as is equivalent to the power developed during the expansion, the air becoming more and more refrigerated as it is more and more expanded, and its pressure becoming less and less in the compound ratio of its expansion and refrigeration, so that the power developed during the expansion will be less than that exerted during the compression by the amount of the lessening of the pressure due to the refrigeration.

As the air on which the operations of compression and expansion are performed is taken from the atmosphere, the atmospheric pressure is their lower limit of pressure, and the final pressure of expansion should always equal it. There is, however, no upper limit of pressure, the compression being conceivable to any degree, and the higher this upper limit the greater will be the expansion.

The greater the expansion of a given mass of air expanded without receiving heat, the greater will be its refrigeration, because the more it is expanded the more power it will develop, and the refrigeration is directly proportional to this power. But the degree of expansion possible for the air can only equal the degree of compression it received, or, in other words, the compression and the expansion can be only between the same pressures, and will have an invariable relation. And as the refrigeration is proportional to the expansion, and as the expansion is proportional to the compression, the refrigeration will be proportional to the compression also. Hence, as the power producing the compression is the cost of the refrigeration, there is no economic gain in the production of a given quantity of refrigeration represented by mass of air multiplied by fall of temperature by giving the air a greater degree of compression in order that it may have a corresponding greater degree of expansion. All degrees of expansion and compression have the same economic value; that is to say, the expenditure of the same power in compressing a given mass of air, let the degree of compression be what it may, produces the same quantity of refrigeration by its corresponding expansion.

If, however, the object be merely to produce the minimum temperature in the expanded mass of air, then its compression at constant temperature should be carried to the highest practical limit in order that its expansion may be proportionally great and its resulting temperature correspondingly low. Nevertheless, nothing is economically gained or lost as regards quantity of refrigeration so produced, the power cost being always proportional to this quantity and unaffected by the final temperature. The minimum temperature of compression is, of course, the atmospheric temperature.

The power developed by the expanding air is, of course, applicable to the compression of air in conjunction with power derived from other sources.

The entire refrigerating effect is produced by the conversion of heat into work during the expansion of the air overcoming a resistance; and for the refrigeration to be a maximum, this resistance must never be less than the pressure of the expanding air. Heat and work being mutually convertible in the fixed relation of 789¼ foot-pounds of work as the mechanical equivalent of one Fahrenheit unit of heat, the fall of temperature in one pound of air doing

work by its expansion is one degree Fahrenheit for every ($789\frac{1}{4} \times 0.2382 =$) 187.99935 foot-pounds of work so done.

When the air expands without overcoming any *external* resistance its refrigeration is very slight, being due to only the *internal* work done upon it by its contained heat in overcoming its own cohesion. The experiments of Joule and Thomson on this subject showed that when air expanded without doing external work its temperature fell five degrees Fahrenheit for the difference of twenty-one atmospheres between its initial and final pressures; and that this fall of temperature was directly proportional to the fall of pressure, which would give for each difference of pressure of one pound per square inch, a fall of temperature of 0.01621 degree Fahrenheit.

If the air be not compressed at constant temperature, but have, during its compression, an increasing temperature caused by the work of compression done upon it, and if this additional temperature so obtained be abstracted by external cooling appliances after the compression has ended and before the expansion has begun, then the whole of the work expended in overcoming the pressure due to the heat of compression is lost, for the quantity of air compressed is the same whether the compression be done at constant temperature or increasing temperature, and the power or work recovered from the expansion is the same, because the same quantity of air at the same temperature will be expanded the same degree or number of times in both cases. The power developed by the expansion has a fixed relation to the power exerted in compression only when the compression is done at constant temperature.

If the expansion, instead of being carried down to the atmospheric pressure, is terminated before that pressure is reached, and the air be then discharged with excess of pressure into the atmosphere, whose resistance is consequently less than that of the expanding air, the latter will expand to the atmospheric pressure, and in so expanding will do work, though less in quantity than if expanding against a resistance equal to its pressure, and will undergo a refrigeration proportional to the work done in expanding against the atmospheric pressure. Of course, the atmosphere upon which the work of this expansion is done undergoes a heating equivalent to the refrigeration experienced by the expanding air.

If the compressed air, after having its temperature reduced to that of the atmosphere, be made by mechanical apparatus to commence its expansion at a lessened pressure, in which case the same quantity of air will be expanded down to the same atmospheric pressure, but the work done by its expansion will be less than if the expansion had been commenced at the maximum pressure, and the refrigeration will consequently be less; and, further, the power recovered from the air thus expanded will be less.

To give practical effect to the foregoing principles, a machine has to be constructed consisting of a steam cylinder, if a steam engine be the motor employed for compressing the air, an air-compressing cylinder for the compression of the air, and an air-expanding cylinder for the expansion of the air, as the compression and expansion of the air are not practically manageable in the same cylinder. These two cylinders must be in communication with each other by means of a pipe for the transfer of the air from the former to the latter. The steam cylinder and the air-expanding cylinder are articulated to the same shaft, and this shaft works the piston of the air-compressing cylinder, so that whatever power is developed by the expanding air is recovered for air compression. The air-compressing cylinder must be single-acting, but the air-expanding cylinder can be double-acting and must be fitted with a cut-off valve.

The machine being arranged to work at a given maximum pressure, which is effected by making the cut-off valve of the air-expanding cylinder to close earlier or later in the stroke of its piston, and set in motion, the air-compressing cylinder receives during the indraught stroke of its piston its capacity of air of atmospheric pressure, which it compresses on the return stroke to the

maximum pressure; and this compression may be done at constant temperature if the heat of compression be extracted as rapidly as generated, or at increasing temperature if that heat be not so extracted. These form two cases in making computations of the results obtained, beside which there are mechanical causes inseparable from the use of mechanism which influence these results, and sometimes to a marked degree. In this machine, as well as in all others, there are differences between theoretical prediction and practical performance, but they can be ascertained and allowed for.

First. When the compression is accomplished at constant temperature in the air-compressing cylinder. In this case the tension gradually increases, according to the Mariotte law, from the commencement of the stroke of the piston until the maximum tension is reached, which will always be before the piston arrives at the end of its stroke, the curve of compression being a hyperbola. At the point of maximum tension, the air-delivery valve opens, and the tension remains constant to the end of the stroke of the piston. The work of compression is measured by the mean pressure of the air above the atmospheric pressure from the commencement of the stroke of the piston of the air-compressing cylinder to the point in that stroke where the maximum tension is reached, multiplied by the distance from the commencement of the stroke to the point of maximum pressure, for after this pressure is attained there is no more air compression. The work done by the piston for the remaining portion of its stroke, measured by the product of that portion into the maximum pressure above the atmospheric pressure, is transferred to the piston of the air-expanding cylinder by means of the air in the connecting pipe between these two cylinders, this intervening air acting as a solid block would act in communicating the pressure from the piston of one cylinder to the piston of the other. Thus, the work done in the air-compressing cylinder after the compression has ceased is directly recovered in the air-expanding cylinder, with the exception of the inevitable loss of pressure due to transferring the air from the one cylinder to the other, caused by the deflections of the air current at the valves of the cylinders and at the bends of the pipe, by the resistance of the interior surfaces of the pipe to air movement, and by the throttling of pressure due to insufficient valve opening. The degradation of pressure due to these causes will be greater the faster the machine works, and should be restricted as much as practicable by giving large openings to the valves, large diameter to the pipe, and few bends. Of course, barring leakage, the same weight of air at the same temperature enters the air-expanding cylinder as leaves the air-compressing cylinder, but the pressure at which it enters the former will be less than that at which it leaves the latter, so that a loss of effect is experienced, measured by the difference of these two pressures.

There is also another loss of effect in the air-expanding cylinder due to the spaces in the clearances and air passages at the ends of the cylinder, in consequence of which the mean pressure on the piston of that cylinder during both the non-expansive and the expansive portions of its stroke will be less than if there were no such spaces, so that the work or power recovered in the air-expanding cylinder will be proportionally less than it would be did these spaces not exist. And, further, the air in consequence of this less work done by its expansion will be less refrigerated. All losses of work in the air-expanding cylinder are not only losses of power which ought to be recovered there, but involve losses of refrigeration for the air, so that the disadvantage is twofold.

Another loss of power may exist, although not necessarily, in the air-expanding cylinder, due to the insufficient opening of its exhaust valve, which causes the back pressure against its piston to exceed the atmospheric pressure. This excess is a total loss of power that ought to have been recovered, but it does not affect the refrigeration, because overcoming it is as much work done by the expanding air as if the power was expended on the crank-pin. This defect only requires a large exhaust valve opening for its removal.

The expanding air in the air-expanding cylinder may receive heat from the atmosphere or from other surrounding bodies, and to that extent its pressure will be increased and also the power it develops proportionally. This is a gain for the power recovered, but a loss for the refrigeration, and should be avoided by clothing the air-expanding cylinder with non-heat-conducting substances.

The power developed in the air-expanding cylinder during the portion of the stroke of its piston previous to the closing of its cut-off valve is the exact reproduction of the power developed in the air-compressing cylinder after the opening of its delivery valve, less the losses just described, and is, therefore, so much power recovered. A further recovery of power then takes place by the expansion of the air through the remaining portion of the stroke of the piston of the air-expanding cylinder, and that this recovery may be as large as possible, the expansion must be continued down to the back pressure against the piston. The power thus recovered is measured by the product of the mean pressure of the expanding air above the back pressure into the portion of the stroke of the piston during which the expansion is operative, and corresponds to the power expended in compressing the air in the air-compressing cylinder, less the losses due to lessened pressure before expansion commences, to the waste spaces in the air-expanding cylinder, to the excess of the back pressure over the atmospheric pressure, to not expanding the air down to the back pressure, and to the refrigeration of the air itself due to the work of its expansion, the latter only of which is considered in a purely theoretical investigation of the subject, as it results inherently from the working of the machine. The entire refrigeration of the air up to the instant when the exhaust-valve opens at the end of the stroke of the piston of the air-expanding cylinder is due to the power developed by the expanding air from the point in the stroke at which the cut-off valve closes to the end of the stroke, calculated down to the back pressure against the piston; if the expansion in the cylinder has been carried down to the atmospheric pressure, no more refrigeration can be obtained; but if, on the contrary, the pressure of the expanding air at the end of stroke of the piston is greater than the atmospheric pressure, there will be a further refrigeration of the air when the exhaust-valve opens, due to the work of expansion that the air will perform in expelling itself from the cylinder into the atmosphere. But as the atmospheric pressure is less than that of the air discharged into it, the latter will not develop as much power as though the expansion had been continued in the cylinder down to the atmospheric pressure, and, consequently, the total or final refrigeration of the air will be less than in that case; nevertheless, the additional refrigeration gained by the discharge of greater pressure into the atmosphere will be considerable and in proportion to the excess of pressure. Both power recovered, however, and refrigeration will be increased by carrying the air expansion down to the atmospheric pressure.

From the power above the back pressure against the piston, recovered in the air-expanding cylinder, there must be subtracted the power required to work that cylinder and its appendages, *per se*; that is to say, to overcome the friction due to the weight of its moving parts and to the tightness of its packings; the remainder is only what is recovered on the crank-pin. This friction power is chargeable to only the portion of the stroke of the piston from the closing of the cut-off valve to the end of the stroke, as previous to that closing the power required to overcome the friction in question was supplied by the air-compressing cylinder.

The power compressing the air in the air-compressing cylinder is equal to the sum of the powers exerted in the steam cylinder and in the air-expanding cylinder, less the power required to overcome the frictions of the machine. Consequently, if indicator diagrams be taken simultaneously from the steam cylinder, the air-expanding cylinder, and the air-compressing cylinder, the difference between the sum of the indicated powers developed in the former two and the indicated power shown in the latter will be the power required to overcome all the frictions of the machine.

These frictions are of two kinds. One is that of the machine *per se*, or what is due to the weight of the *unloaded* moving parts and to the tightness of the packings (the air resistance to the moving parts being too inconsiderable to be included in a practical investigation) ; the power to overcome this friction is directly as the speed, the piston pressure being constant for all speeds. The other friction is what is due to the net power, or power applied to the crank-pins, and the power required to overcome it is proportional to the power applied to them. The articulations of the machine when at work are pressed by the pressure producing the net power, which consequently excites friction at those points in the direct proportion to that pressure. These two kinds of friction are entirely independent of each other, and must be dealt with separately in computation.

Finally, there is a loss of theoretically recoverable power due to the precipitation of a large portion of the moisture in the atmospheric air compressed. This air, after compression at constant temperature, cannot hold as much aqueous vapor as before compression, and the vapor is consequently continuously deposited in the form of water as the tension of the air continuously increases, involving a loss of mechanical effect measured by the bulk of vapor thus condensed.

Under purely theoretical conditions the power recovered in the air-expanding cylinder would exactly equal the power expended in the air-compressing cylinder less the power due to the loss of pressure in the expanding air caused by its refrigeration while doing work.

All the foregoing deductions are for the case of constant temperature for the air during its compression, but the temperature may not be constant which forms case —

Second, in which the compression is accompanied by a continuously increasing temperature, the heat equivalent to the work of compression not being abstracted from the air as fast as generated.

In this case the heat has to be taken out of the compressed air after the latter has received its maximum tension and before its expansion has commenced, the abstraction of the heat being performed in the pipe connecting the air-compressing and the air-expanding cylinders. This pipe receives the air from the former cylinder at maximum temperature, and delivers it at the atmospheric temperature to the latter cylinder.

The maximum tension is obtained in the air-compressing cylinder, and is acquired before the piston of that cylinder reaches the end of its stroke ; yet, notwithstanding this, the compression goes on during the remainder of the stroke, but without increase of pressure, because when the maximum pressure is obtained, the delivery valve opens, putting the interiors of the air-compressing cylinder and of the pipe in common ; and as in the latter the air is undergoing continuous shrinkage of bulk owing to continuous decrease of temperature, the piston of the air-compressing cylinder maintains the constant maximum pressure by continuously squeezing up the air of falling pressure due to the falling temperature ; consequently the whole of the power developed in the air-compressing cylinder—that is, the power measured by the product of the mean pressure in the cylinder above the atmospheric pressure, into the entire stroke of its piston—is employed, not only in forcing the piston of the air-expanding cylinder from the commencement of its stroke to the point where the cut-off valve closes, but in compressing air, and it is the heat of this compression which is generated in the air-compressing cylinder and has to be extracted.

The above considerations are not modified by the fact that part of the heat of compression may be taken out of the air before it leaves the air-compressing cylinder, as the pressure on the indicator diagram would thereby be proportionally reduced.

Now, as the power developed in the air-expanding cylinder is from a given weight of air of the atmospheric temperature at a given pressure, irrespective of what may be the temperature of this weight of air at the given pressure

when it leaves the air-compressing cylinder, it is evident that the power recovered by the expanding air is, under the circumstances, a fixed quantity, let the power expended on the compression be what it may; so that whatever excess of power is developed in the air-compressing cylinder due to the greater bulk there of the given weight of air to be compressed to the given pressure, which greater bulk is caused by the greater temperature, is entirely lost. That is to say, the difference of power between what is required to compress a given weight of air at constant temperature to a given pressure in the air-compressing cylinder, and what is required to there compress the same weight of air at increasing temperature to the same pressure, is entirely lost.

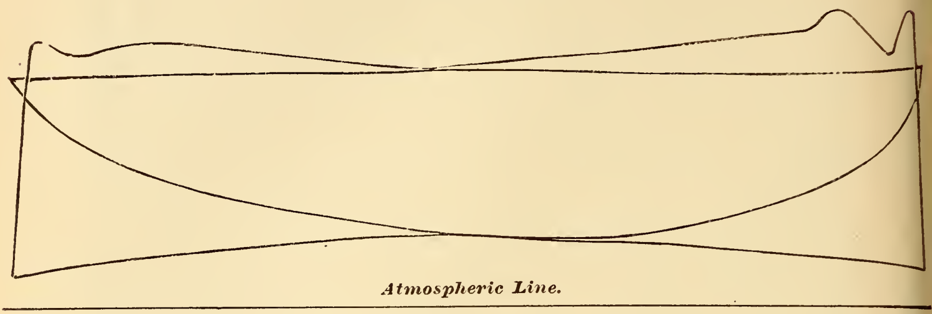
The losses of mechanical effect in the air-expanding cylinder, either in kind or quantity, are entirely uninfluenced by the more or less heat of compression in the air-compressing cylinder, and remain as previously described.

A comparison of the bulk and weight of the experimental machine, with the quantity of refrigeration it produces, even if by more skilful adjustment that quantity were doubled, shows how inefficient is the system of cooling by air expansion when the cost and quantity of the mechanism to furnish it are considered. This inefficiency is due to the fact that, owing to the low specific gravity and high specific heat of air,—a mixture of fixed gases—an enormous machine is needed for the production of but a small quantity of refrigeration; consequently, when large quantities of cold air are required for ventilation on board ship, and for respiration by the numerous personnel embarked, the weight and bulk of an adequate machine make its employment out of the question. For a hospital its use is practicable for cooling an apartment in which air dry and much refrigerated is required for the successful treatment of certain diseases and for surgical operations in hot weather. Its use is also practicable for the refrigeration of large apartments, indeed, the entire holds on board ship, in which fresh meats and fresh vegetables are to be transported, as in that case there is required only cooled air enough to compensate the increase of temperature by radiation from the walls of the apartment and by inleakage of external air through them, which, by proper non-heat-conducting covering and by being made air-tight, can be reduced to an insignificant amount.

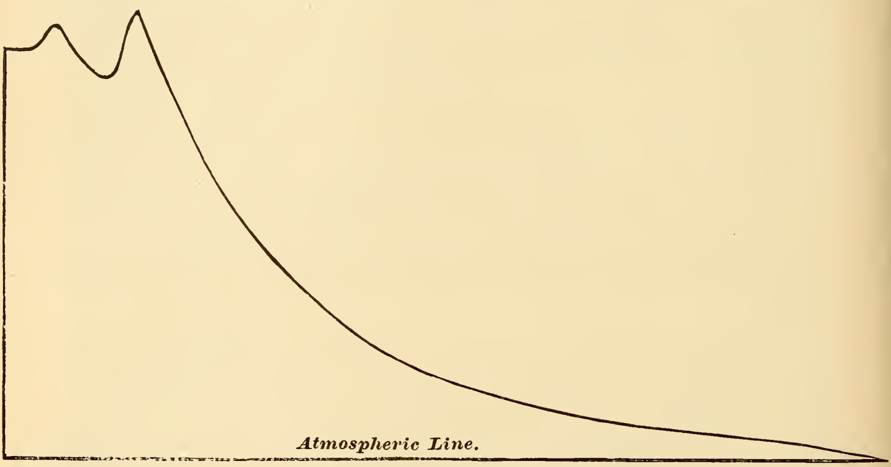
The great practical advantage of the air-refrigerating machine is its simplicity, and the fact that air, the substance operated with, is found everywhere without cost and is innoxious. But, if air be all-present and abundant, water is not, and that is required in considerable quantities for absorbing the heat of compression. This heat can indeed be taken up by the external atmospheric air, but the operation is excessively slow and requires an enormous extent of pipe surface between the air-compressing and the air-expanding cylinders, besides involving a maximum loss of power in performing the compression. The temperature, too, of the air-compressing cylinder would be inconveniently great, in fact, impracticably great, if the compression were carried to any high degree.

AIR-REFRIGERATING MACHINE.

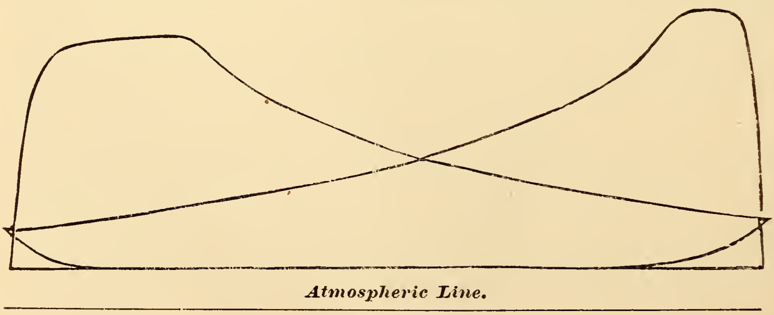
INDICATOR DIAGRAMS FROM THE THREE CYLINDERS SHOWING THE DISTRIBUTION OF THE PRESSURES.



Indicator diagram from steam cylinder. Scale 36 *pounds per square inch per inch.*



Indicator diagram from air-compressing cylinder. Scale 59 *pounds per square inch per inch.*



Indicator diagram from air-expanding cylinder. Scale 59 *pounds per square inch per inch.*

THE EDISON ELECTRIC LIGHT ON BOARD THE U. S. FISH COMMISSION STEAMER ALBATROSS.

EXTRACTS FROM A REPORT MADE BY LIEUT. SEATON SCHROEDER, U. S. N.

There are 136 Edison incandescent lamps in place on board this vessel; of that number, under ordinary circumstances 40 to 45 are generally in operation the greater part of every evening, beginning at dark and ending at about 11 P. M.

During the quarter ending March 31, 1883, eighteen lamps have been disabled, as follows:

10 Broken in handling.
4 Burned out.
1 Burned out by short circuiting of two branch wires.
1 Gradually unscrewed from socket, owing to vibration of hull, and fell on deck, breaking the glass and filament.
1 Carbon filament broken by caulking the deck above.
1 Carbon filament broken while experimenting.

The invoice price of each lamp being one dollar, the additional cost of illumination on account of breakage of lamps has been $18.00, over and above first cost of plant.

During the quarter the dynamo-machine has run 540 hours. Of the 136 lamps in position 34 have been in operation the whole time, or 540 hours each = 18,360 hours in all; of the remainder, the hours of incandescence have been as follows:

2 — 440	hours	each	= 880	hours.
4 — 410	"	"	= 1,640	"
22 — 340	"	"	= 7,480	"
8 — 100	"	"	= 800	"
20 — 50	"	"	= 1,000	"
18 — 10	"	"	= 180	"
			= 11,980	"
34 — 540	"	"	= 18,360	"
Total, . . .			= 30,340	"

The running expense in lamps has therefore been $\frac{\$18}{30340} = 59$ one-thousandths of a cent per lamp in operation per hour. For illuminating the entire vessel the running expense in lamps has been $\frac{\$18}{540} = 3\frac{1}{3}$ cents per hour.

The life of the lamps that have burned out has been as follows:

No. 49 (8-candle power)	. . . .	92 hours.
" 90 (8-candle ")	. . . .	369 "
" 68 (16-candle ")	. . . .	195 "
" 41 (8-candle ")	. . . .	99 "

A mean of these would obviously be a very unfair showing of the average life of the Edison lamp. The imperfect ones give way first, and a correct

average, of course, can only be had by waiting to consider the best as well as the poorest. It is only fair also to add that the breakage by accident has been greater than will probably continue to be the case, the crew being extremely raw, green, and unthinking. In handling the lamps (frequently without authority) they have apparently used more force, as a rule, and less dexterity than the occasion required, simple as their manipulation is. Familiarity with the light will doubtless decrease this source of expense.

Furthermore, the lamp that was disabled by caulking overhead was purposely left in place to test its safety under those conditions, it being attached to the deck that was being caulked; the burning of one by short circuiting occurred before the installation of the system was completed, and resulted from the loose ends of two branch wires coming in contact; the destruction of a third occurred during, and was apparently caused by, some experiments, which proved an abnormal condition for an incandescent system of illumination.

As shown above, only four of the eighteen have burned out, which would reduce the legitimate running expense to $\frac{\$4}{30340} = 13$ one-thousandths of a cent per lamp in operation per hour, or $\frac{\$4}{570} = 74$ one-hundredths of a cent per hour, for lighting the vessel.

Some of the globes have begun to be discolored by the wasting of the filaments (Crooke's effect), but not sufficiently to affect sensibly the amount of light given out.

Apart from questions of economy, the light commends itself strongly for use on shipboard. Its chief advantages over the means of illumination in common use afloat, are:

1. The absence of heat, smoke, smell, and dirt, and the non-consumption of oxygen; important points at all times, and especially in bad weather, when hatches are closed.

2. The almost absolute immunity from danger of fire; even in cases of short circuiting or arcing between two branch wires, which are the only ones liable to this mishap, the destruction of the safety-plug is simultaneous with the passage of the small spark, the circuit being thus instantly broken, and further danger avoided.

3. The great convenience of having it ready to turn on in any place, including the magazine passage, holds or store rooms, where otherwise an oil lamp would have to be used with its peculiar characteristics of dimness, dirt, and danger.

4. Its ability to remain in operation under water, when it may frequently be useful in examining or repairing a ship's bottom, or clearing a hawser from the propeller at night. It is likewise unaffected by rain or wind.

The steadiness of the light and its softness combine to make it most agreeable to the eye, and excellent for reading or working on a chart. The brilliance, of course, depends upon the velocity of the dynamo-machine, and the amount of resistance introduced into the circuit of the field magnets; but with average incandescence it is found that ordinary print can be read with comfort on a table by the light of one 16-candle, or two 8-candle lamps, four feet above it, fitted with porcelain shades. With one 8-candle lamp in that position, the print cannot be easily read without a tin reflector, which materially affects the dispersion of the light about the room. Four 8-candle lamps, with shades, situated four feet above a mess table seating twelve persons, illuminate it brilliantly.

The berth-deck of the vessel is 42 feet long, 23 feet average breadth, and 8 feet high. It is lighted by six 8-candle lamps, three on each side. They illuminate it thoroughly, so that the numbers on the bags or hammocks can be read with perfect facility in any part or in any position.

The fore-hold has, on the after bulk-head, one 8-candle lamp on each side, with tin reflectors. By the light of one of them, any piece of gear or object of any kind on the same side of the hold can be immediately recognized

throughout its length (25 feet), and could easily be picked out at a greater distance.

Throughout the entire vessel, the efficiency of the illumination is the same, and is a great source of convenience and comfort to all serving on board.

The great convenience of the portable hand and stand lamps need not be dwelt upon, as that is the same on shipboard as on shore. One of 16-candle power has been tried as a submarine light, its flexible cord and socket being wrapped with insulating tape. It has been under water, in all, sixty hours so far, with perfect impunity. At sea, with clear water, its light has been traced until it reached a depth of 100 feet; and after being in operation all one night at a depth of 150 feet (the length of the cord), it was found to be still air- and water-tight when hauled up, and is apparently in as good condition now as those in ordinary use.

Extracts from a Report made by Passed Assistant Engineer George W. Baird, U. S. N.

The economy of the Edison incandescent system of lighting is a question of commercial as well as engineering importance, and as this is the first Government vessel to utilize this important invention, I have considered it necessary to make more than the usual test of the machinery, that we may obtain figures which will enable the Commissioner to judge intelligently as to its real and comparative value.

First, the *Plant* consists of an engine of the Armington and Sims make, having a single cylinder of 8½ inches diameter of bore and a stroke of piston of 10 inches. The engine is horizontal, is mounted on a rigid cast-iron bed-plate, and has a centrifugal governor in the fly-wheel; the governor weights are connected to internal and external eccentrics and operate by shifting these eccentrics in equally angular and opposite directions, which diminishes the throw of the valve (without effecting the lead), and thus effects a shorter cut-off. It is sensitive, and, so far as I can measure, regulates the speed of the engine to 300 revolutions a minute without regard to the initial pressure on the piston or the resistance on the dynamo.

Second, a Z dynamo, having its field magnets vertical, the armature revolving in the field between the magnets, in the induced current. A resistance box is placed in the circuit of the magnetic field which regulates the pressure, and, by altering the switch on the resistance box, the incandescence of the lamps is raised or lowered at pleasure. The object of this method is to equalize the internal and external resistance, that the maximum economic effect may be realized, hence the great economy of the Edison system. For example, the dynamo is designed for 120 B lamps of 8-candle power each, and if only 60 lamps be in circuit the resistance of the circuit will be doubled and the field resistance must be switched in to balance it.

Third, there are 139 eight candle-power B lamps of 69 ohms resistance each, placed in multiple arc, and so distributed through the vessel as to illuminate every place where light is required. There are four circuits (of copper wire) from the dynamo, viz. a double circuit—main—on each side of the ship, for the forward lamps; a double circuit, on each side of the ship, for the after lamps; a single independent circuit for the outside lamps with the switch in the engine room, and an independent circuit for the engine room. The mains are not only double circuits, but each main consists of two No. 10 wires. The advantage of this system of wiring is manifest; in the event of breaking a wire, from collision or other cause, the remaining wires would be ample to carry the current. The mains, however, are brought together and soldered where they are attached to the binding posts of the dynamo. The wires are insulated with cotton cloth and white lead, and when passing through damp places they are further protected by rubber tubing. On each main wire, and near the dynamo (as well as near each group of lamps), is a "cut-out plug" or "safety catch,"

which contains a short piece of fusible alloy. The office of this plug is two-fold; it may be used as a switch to cut that wire out of the circuit at pleasure, and also to prevent the heating of the wires beyond the fusing point of the alloy (400 degrees), thus rendering the system harmless as a fire agent. These "cut-outs" are essential, as the copper wires would, in event of a short circuit, melt and set fire to adjacent woodwork.

The absolute safety of the Edison system, against injury to human life, commends it very highly. The low pressure of 51 volts is insufficient to pass through a man's body, and can, therefore, never injure him.

MANNER OF MAKING THE EXPERIMENTS.

By means of a steam engine indicator I measured the power required to run the engine and dynamo, the current being switched off. By the same instrument I measured the indicated power required to run 45, 50, and 70 lamps, respectively. . . . By deducting from these experiments, respectively, the power required to run the engine and dynamo, we obtain the power applied to the shaft, and from this quantity we deducted the friction of the load, leaving, as a remainder, the net powers required to revolve the armature, in the magnetic field, with 45, 50, and 70 lamps in circuit.

DISTRIBUTION OF THE POWER.

Power required to run the engine and dynamo	3.56
Indicated horse-power required to run 45 incandescent lamps	5.79
Indicated horse-power required to run 50 incandescent lamps	5.85
Indicated horse-power required to run 70 incandescent lamps	6.92
Net horse-power applied to the revolution of the armature in the magnetic field, using 45 incandescent lamps	1.80
Net horse-power applied to the revolution of the armature in the magnetic field, using 50 incandescent lamps	1.85
Net horse-power applied to the revolution of the armature in the magnetic field, using 70 incandescent lamps	2.84
Mean number of incandescent lamps per indicated H. P. using 45 lamps	7.77
Mean number of incandescent lamps per indicated H. P. using 50 lamps	8.50
Mean number of incandescent lamps per indicated H. P. using 70 lamps	10.11
Mean number of incandescent lamps per net H. P. using 45 lamps	25.
Mean number of incandescent lamps per net H. P. using 50 lamps	27.02
Mean number of incandescent lamps per net H. P. using 70 lamps	24.63

The wires being fixed, their resistance may be considered a constant quantity and the only variation as existing in the engine and dynamo; the distribution of the power as above recorded may, if necessary, be verified by electrical measurements on the wires.

RELATIVE ECONOMY OF THE LAMPS.

The cost of running the incandescent lamps, as compared with coal-gas lighting, is a matter of commercial as well as engineering interest, and it is my purpose to confine the comparison to these objects alone. From the quantities determined and recorded above, these comparisons are made, candle-power for candle-power.

So far the greatest number of lamps in operation at one time has been 70; we ordinarily use from 45 to 50. The number of lamps per indicated horse-power increases with the number of lamps used, for the reason that the engine works more economically at higher powers.

The comparison between these incandescent lamps and light from coal gas, as measured by a photometer, is not a fair one, inasmuch as the gas-burner itself (to say nothing of part of the fixture) is under the jet and casts a shadow underneath, while the Edison lamps are inverted and the shadow is above. As

the light is used under the lamp, a larger percentage of light from the inverted fixture will be cast upon the work beneath, and for this the photometer makes no reduction.

Although the B circuit is installed to give 8-candle power lamps they really emit about 10, which is also an unbalanced account in favor of the electric lamps.

The cost, in coal, of a horse-power developed by the dynamo engine has been arrived at by calculating the quantity of steam passed through the steam cylinder, and reducing this to pounds of water and dividing this by the pounds of water evaporated by a pound of coal. Had steam been used for lighting alone, this calculation would have been unnecessary, but as steam was used, from the same boiler, to warm, ventilate, and light the ship at the same time, the writer adopted this method of separating the respective powers. From these indicator diagrams I have calculated that a horse-power costs 30.7 pounds of water or 3.41 pounds of coal per hour. The cost of the coal was $4.60 per ton, and the lubricating oil 65 cents per gallon. The consumption of oil is one quart in six hours, so that the cost to us, to run the dynamo during the 70 lamp experiment, was $(\frac{460}{2240} \times 3.41 \times 6.92) + \frac{65}{4 \times 6} = 7.553$ cents per hour or $(\frac{7.553}{70}) = 0.1079$ cents per lamp per hour or $(\frac{0.1079}{8}) = 0.0135$ cents per candle power per hour.

The coal-gas company of Washington supplies gas of 17 candles power, used from a 4 foot bat-wing burner, at $1.75 per thousand cubic feet. The cost of such a jet of gas then becomes $(\frac{175 \times 4}{1000 \times 17}) = 0.041176$ cents per candle-power per hour, or a little over three times what the Edison incandescent light is costing us on board this ship.

I have purposely omitted the cost of labor and the interest on the money invested in the plant, as we have no additional men for running the dynamo nor engine, the officer on watch attending to it in addition to his other duties. The interest on the plant at six per cent. is only ($3500 $\times$ 0.06 =) $210. We use about 50 lamps about six hours a day, so that the interest on the money invested is about $\frac{2}{100}$ of a cent per candle-power per hour, or hardly worth considering.

MUD DOCKS AT VIZAGAPATAM, INDIA.

Contributed by Commander P. F. Harrington, U. S. N.

Docking.

When a ship is to be docked, she is towed up the river from her moorings to near the dockyard. A large ditch of a little more than the ship's length and breadth, and deep enough to contain water of the depth of the ship's draught, is dug in the mud at right angles to the river. At high tide the water flows into this ditch and forms a basin into which the ship is floated or dragged. Two rows of strong stakes are now driven in across the entrance to the ditch and common palmyra, date, or bamboo mats tied to them. The space between these is filled up with sand and silt, and thus communication is cut off between the dock and the river. The basin in which the vessel is now floating being surrounded by a high mud bank formed by the mud excavated from the dock, the level of the water in the basin is raised by coolies throwing some of the mud of this bank into the basin, and thus raising the bottom of the basin, which must in consequence elevate the water in the basin and the vessel floating on it. The vessel is by this process elevated considerably higher than the level of the water in the river or inlet. If the bottom of the ship requires much repair, and has, therefore, to be elevated more than usual, more earth is dug up and heaped high against the sides of the vessel, leaving two or three yards of space in the dock unfilled fore and aft, and then water conveyed thither through a small channel is baled into the aforesaid spaces. This water also enters under the vessel and elevates it to the height of the mud heaped against it on either side.

Strong beams of wood are by the following process next placed transversely under the ship at two, three, or four different places, varying according to the length of the vessel. At the spot where the beams are to be placed, a mine so called (ghanee) is dug under the vessel from side to side, coolies working from either side of the ship at the same time until they meet each other under the ship's keel. Three beams one after the other are then dragged by a rope tied to the end of each under the keel and laid there one by the side of the other. The same thing is done, fore, aft and midships, or in more places if necessary. The mud on the sides of the vessel is then dug away to the level of the surrounding ground and the sides of the vessel caulked or otherwise repaired. After this is done—or simultaneously, if the vessel is to be repaired quickly—the mud under the bottom of the vessel is excavated except near the beams and the ship's bottom repaired; and the beams also, if necessary, are removed from one place to another to allow repairs where they were originally placed. When the ship's bottom is under repair, several props consisting of the stumps of palmyra trees are placed against or slightly under the vessel to prevent her from rolling over.

Undocking.

Ordinarily four sets of hawsers are used, each being coiled into the shape of a cone, the diameter of which at the base is about five or six feet, and where it touches the vessel a foot or two less. As the coiling is going on the cone is made solid by filling it in with mud. One cone is placed under the starboard bilge forward, another under the same bilge aft, and a third and fourth in corresponding positions on the port side. Four cones are ordinarily used at

MUD DOCKS AT VIZAGAPATAM.

Vizagapatam, unless the ship is of more than three hundred tons burthen—when their number is increased according to the length and size of the ship. After this is done the transverse beams are one by one withdrawn, the dock having been first dug to the required depth, and then the vessel, which now rests entirely on these cones, is gradually lowered by withdrawing *simultaneously* from the base of each cone a coil or fake by which the four cones supporting the vessel bodily subside at a low speed and the vessel along with them. The cross-bund being now removed the water from the inlet flows into the dock and floats the vessel at high tide.

The docking and undocking of a vessel of two hnndred tons ordinarily costs about 50 rupees,* including the rent of the dock and the props and beams; and the cost increases in proportion to the size of the vessel and its draught.

Vessels of four or five hundred tons burthen have been built and undocked at this port in the manner set forth above, such as the Gallant Neil, the Lady Sale, etc.

If, on account of any extraordinary season, a sufficient quantity of water does not flow into the dock, which is very rare, four or five large casks rented or belonging to the vessel, are tied fore and aft at low water, or if large casks are not procurable, a large boat or canoe is tied on when filled with mud, and this mud being gradually removed the rising of the canoe or boats assists in getting the vessel afloat.

*A rupee (silver) is about 39 cents, and is the current coin and unit of value throughout India.

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ANNALEN DER HYDROGRAPHIE UND MARITIMEN METEOROLOGIE.

PART IX., 1883. Researches in meteorology and ocean physics in the American-Arctic archipelago by various English Arctic expeditions, from 1819 to 1854. Researches in meteorology and ocean physics during the expedition of the Vega, 1878–79, and in the winter-quarters at Serdze Kamen. Log-notes of various German vessels. Additions to the description of the eastern part of Tsugar Straits, Japanese Islands, from the report of the British surveying ship Flying Fish. Hurricane at Apia, Samoan Islands, March 24th and 25th, 1883. Comparison of the weather in North America and Central Europe for June, 1883.

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PART XI., 1883. The daily changes in the force of the wind over the land and over the sea. Meteorological and hydrographic results of the Austrian North Polar Observation Station at Jan Mayen. New deep-sea investigations; contains accounts of the deep-sea soundings of the U. S. C. S. S. Blake and the U. S. S. Enterprise in the Atlantic ocean. Comparison of the weather in North America and Central Europe for August, 1883. Hydrographic notices treating of encounter with ice in the eastern part of the South Atlantic. Plate of surveys, Chili, West Channel, by the Italian corvette Caracciolo.

BULLETIN DE LA RÉUNION DES OFFICIERS.

DECEMBER 8, 1883. Description of the Chinese ironclad Ting Huen, built at Bredof, near Stettin. The military organization of South Australia.

ENGINEER.

OCTOBER 5, 1883. The Design, Specifications, and Inspections of Ironwork: a paper read before the Society of Engineers, by Mr. H. W. Pendred.

OCTOBER 19. A New Form of Flexible Band Dynamometer, by Prof. W. C. Unwin.

OCTOBER 26. A description of the new cruisers for the U. S. Navy.

An editorial in the same number contains a wholesale condemnation of the hull, armament, machinery, and boilers of the "Chicago," concluding with the following remarkable passage: "We see in the boilers and machinery of the ship, to say nothing of the hull, a manifestation of that desire to be original at any cost which has done so much harm already in the U. S. Navy. The experience of the gentlemen who have prepared these designs can be as nothing compared with British engineers. If no such engines are to be found in a British ship, the U. S. Naval Advisory Board may rest assured that there is good reason for the fact; if no boilers of the type were ever made and sent to sea at this side of the Atlantic, the circumstance bears its lesson. Those entrusted with the design of the 'Chicago' have not availed themselves of the experience acquired in this country at a great expense, and they will regret the fact."

Notwithstanding the original argument given above, together with the assumed superior brilliancy of the English engineers, it is thought that the work of building the Chicago will still go on.

NOVEMBER 2. Peck's revolving piston pump.

A novel design of pump combining the principles of the ordinary plunger type and the rotary pump.

NOVEMBER 9. Sand-blast file-sharpener.

A description accompanied with illustrations of the operation of sharpening files by means of Tilghman's sand-blast process.

NOVEMBER 16. Giffard's Injector.

A short paper giving an easy and practical demonstration of the formulæ connected with Giffard's injector, by Prof. James Lyon.

Higgs' suspension for incandescent lamps.

A neat suspension for incandescent electric lamps, designed by Mr. Paget Higgs. This arrangement permits a considerable amount of motion to take place in the lamp, and is free from the objection to the ordinary Swan suspension, as the lamp cannot become unhooked.

Uniformity of rotation in electric lighting engines.

In considering the complaints made by electricians as to the want of uniformity in the rotation of the engine, and to the consequent want of uniformity in the rotation of the armature of the dynamo-machine, we are much inclined to think that both time and money are likely to be wasted if either is further expended in scheming elaborate cut-off and governor-gear. Some engines without anything of the kind have given a great deal of satisfaction, while others with every refinement have failed. This is the case simply from the fact that the engine in common use has been one of ample power and has been selected for contingencies, while in the refined engine, the power required has been carefully calculated and compared with the indicated horse-power of the engine. Things are, in short, in such cases cut fine, and the power of the engine at normal speed and pressure is so near the work it has to do that it must be nursed and the firing performed by a skilful fireman. For electric lighting, as well as for other dead-pull work, strong, well-made engines are required; the admission and cut-off of the steam should be tolerably quick and precise, and a powerful governor should be employed.

On the Stability of Ships at Launching.

A valuable paper on the above subject was read before the Institution of Engineers and Shipbuilders, by Mr. J. H. Biles.

NOVEMBER 23. Riveted joints.

In an editorial, discussing the relative advantages and disadvantages of hand and machine riveting, attention is called to the fact that opinions on this subject

have held sway long enough, and that it is time that some definite statement of results obtained in practice, as to the cost and efficiency of the different methods, should be made public.

NOVEMBER 30. Tweddell's hydraulic ship-riveting machine.

A description of a powerful machine for closing up rivets in comparatively inaccessible places, about the covering boards and waterways of iron vessels.

DECEMBER 7. On the Destructive Distillation of Coal and Transformation of its Nitrogen into Ammonia.

An abstract from a paper by M. Scheurer-Kestner, read before the Paris Academy of Sciences.

Armer's vertical boiler.

The object of this design is to obtain in a vertical boiler the greatest possible efficiency in the tube-heating surfaces. For this purpose the tubes have a helical twist given them, which does not influence the facility for cleaning, while it causes greater impingement of the gases against the tube-walls, and gives more freedom for expansion and contraction than straight tubes.

DECEMBER 14. Lang's wire rope.

In this method of laying wire rope, the strands and the rope are laid in the same direction, while in the ordinary manner they are laid in opposite directions. By the former arrangement a much larger wearing surface is secured, and a correspondingly increased duration; for, while in the common rope the area of bearing surface is so restricted that the outer wires break after a comparatively small wear, and before the inner part of the rope is much strained, the strands of the Lang rope continue in a serviceable condition until they are worn down too thin to resist the strain.

The First Law of Electrostatics.

A paper on this subject by Prof. Thompson, in which he shows that if electricity be considered as a self-repulsive medium, a surplus in one place and a deficit in another would give rise to motion between them, *i. e.*, attraction. This inference, as well as many other electrical phenomena, were illustrated on the same hypothesis by means of self-repelling magnet poles buoyed with cork and floated on oil. The repelling poles tend to a uniform distribution of themselves throughout the surface of the oil, which would correspond to space in nature. A surplus of poles at one place led to movement until the distribution was uniform. Prof. Thompson pursued the hypothesis to the inference that electricity is either ether or ether electrified; the former supposition being the more probable.

ENGINEERING.

OCTOBER 12, 1883. Deep-sea sounding and dredging.

Illustrations and descriptions of the following American machines at the Fisheries Exhibition, viz., Sigsbee's deep-sea sounding machine; hand sounding machine, designed by Lieut. Z. L. Tanner, U. S. N., for sounding by wire in moderate depths; and an arrangement by which a number of Negretti and Zambra's deep-sea thermometers may be attached to one line and tripped by means of a messenger. By this device a series of temperatures at different depths can be taken simultaneously on one wire by a single operation. This arrangement is the combined work of Lieut. Tanner and Passed Asst. Eng'r Bayley, U. S. N.

OCTOBER 19. Manganese bronze screw propellers.

The advantages claimed for this metal are that thinner blades may be used, and that although the first cost is greater, they are cheaper in the long run, owing to their greater life and the value of the old material.

NOVEMBER 2. Siemens' dynamo with friction driving gear.

Both belt and rope transmission are unsuitable for marine installations on account of the extent to which the electric light is used on board ship and the limited space at the disposal of the electrician. To remedy this, Mr. Raworth had invented a new method of driving electric generators by means of frictional or rolling contact. The pulley on the armature spindle is composed of disks of paper powerfully compressed between two wrought-iron cheeks and turned to a smooth cylindrical surface. It runs in contact with a large cast-iron pulley, which is also the fly-wheel of the engine, and the two are maintained in intimate connection by a pair of tightening bars. The first machines driven in this manner fed 60 lamps, and were placed on board the S. S. Aurania, where they have answered admirably.

The new system of American ordnance.

A notice of the new 6-in. gun states that the work of designing it was very systematically gone about; the quality of metal procurable, strain that such metal would endure, and the weight allowable to the gun, being all carefully studied. The most noticeable departure from European construction consists in the fact that neither the breech-block nor trunnions touch the tube. By keeping the breech-block clear of the tube, the latter is relieved of the recoil strain.

NOVEMBER 16. Prevention of incrustation in steam boilers.

The report of the Chief Engineer of the Manchester Steam Users' Association enters largely into the subject of the prevention of incrustation in land boilers. The report stated that the numerous patent anti-incrustation compounds should be used only with the greatest caution, many of them proving actually injurious to the boiler on actual trial.

NOVEMBER 30. The electric lighting of the S. S. Adelaide.

DECEMBER 7. Joicey's boiler.

A description of a locomotive type of boiler adapted for marine purposes, or for situations where great evaporative power is required in small limits. The boiler is of the vertical type, with a fire-box formed by two truncated cones united by their smaller ends. By this arrangement a space is left between the furnace and the shell, into which a man can get for the purpose of inspection and cleaning. A short barrel is riveted to one side of the shell, and a part of the upper cone of the fire-box is flattened to act as a tube-plate; the products of combustion pass through a number of small tubes in this barrel and go back through the boiler by a flue to the uptake. In a practical trial of a boiler of this kind, 5 ft. in diameter by 11 ft. 6 in. high, steam was raised in 45 minutes, and 937 pounds of water were evaporated in 40 minutes, or at the rate of 9.87 pounds of water per pound of coal. The boiler was fifteen months old, and, though it has been at work both with fresh and with salt water, it was perfectly clean and free from scale.

DECEMBER 14. The Generation of Steam and the Thermo-dynamic Problems Involved.

An abstract of a lecture delivered before the Institution of Civil Engineers, by W. Anderson, C. E.

GIORNALE DI ARTIGLIERIA É GENIO.

NOVEMBER, 1883. Artillery from its introduction to the present day. Historical exposition of development, especially in Italy.

JOURNAL DE LA FLOTTE.

July, 1883. The frigate Le Talisman anchored at Teneriffe, May 31. Her explorations on the coast of Morocco, between Mogador and the Canaries, have been more successful than the preceding ones. The depths of 1000 and 1500 meters have furnished us with sponges and fish in great numbers. Those of 1500 and 2000 meters have given us extremely rare fish, and living coral of the greatest value. The work has been greatly aided by the sounding-machine perfected by M. Thibaudier, the naval constructing engineer, as well as by the cable furnished by the Chatillon and Commentry Company.

Le Talisman has since returned to Palmas, where there is a valuable zoölogical museum, and thence has proceeded to the Cape Verde Islands.

September 2, 1883. Le Talisman, charged with the scientific exploration of the Sargasso sea, arrived at Punta Delgada (Azores) August 17. Although the vessel has traversed the Sargasso sea in the parts said to contain the most wrack, the members of the scientific commission have not had their theories verified. It is not only in scattered bunches that the Sargasso appears for nearly 300 leagues, but in the canal that separates Pico from San Jorge there has been found at the depth of 1400 meters a fauna as abundant and as varied as that of the coast of Africa.

October 14, 1883. The Belleville boiler. [See translation by Professor J. Leroux, of article on the Belleville boiler, in Vol. IX., No. 1, Proceedings of the United States Naval Institute.]

In view of the excellent results obtained with the Belleville boilers on the Voltigeur (despatch-boat with engines of 1000 H. P.), which, after an active cruise along the Tunisian coast and in the Levant, has been sent to the Senegal coast and the Gaboon river, the French Ministry of Marine has just ordered a set of boilers of the same system, of 2100 H. P., for the frigate l'Hirondelle, and a second set of 450 H. P. for a gunboat of the Lionne type. Besides these, MM. Belleville et Cie. are building in their shops two other sets of an aggregate H. P. of 3800, destined for the frigate Le Milan, whose engines are to work at a pressure of 10 kilogs. the square centimeter.

October 28, 1883. Regulations governing competitive examinations for admission to the French Naval School.

December 16, 1883. The interior sea in Tunis.

At the meeting of the Société des Ingénieurs Civils, on the 16th of November, Commandant Roudaire explained his project for an interior sea in Africa.

The projected sea will lie to the south of the provinces of Constantine and Tunis. It will occupy what is now known as the basin of *chotts*, which consists of three great depressions near the Gulf of Gabes, and which is manifestly the floor of an ancient sea; this is abundantly proved by the thick bed of salt that is found there. Commandant Roudaire scientifically demonstrates that the banks of the Melrir *Chott* are about 30 metres below the sea level.

Once flooded, the *chotts* will have a depth of water of from 22 to 27 metres, while near Sfax there is only from 1 to 16 metres.

The completion of this sea will permit the draining and purifying of a vast tract of land which is now worthless on account of the bogs and salt-deposits. Algeria will at the same time be benefited; for, the moisture-laden air will be condensed against the cold range of the Aurès, whose summits are here and there covered with snow even in midsummer. Herein will exist an advantage over the district of Provence, where the mountain ranges lie north and south, and where, as in the *chott* region of Tunis, the prevailing wind is from the south.

From a political point of view the advantage of the projected sea is that it will constitute a magnificent frontier, 400 kilometres long. It will thus serve

as a check to the Arabs, who now make frequent raids across the *chott* region, retreating afterwards with impunity to the south.

To compensate the loss by evaporation, it will be necessary to run in 187 cubic metres of water per second. The cuttings will be soft earth, and the price per cubic metre would be 50 centimes; a canal of small dimensions would be first dug, and this would be subsequently enlarged by the action of the flowing water itself to the required width and depth. The work could be accomplished in two years and a half. The total volume of cuttings would be 260 millions of cubic metres, representing an expense of 130 millions of francs. Remuneration for the outlay would come from grants of adjacent lands, whose fertility would be considerably increased; from the working of the salt deposits; from the fisheries, and from the rights of transit, etc.—*Revue industrielle.*

JOURNAL OF THE FRANKLIN INSTITUTE.

SEPTEMBER, 1883. The Screw Propeller, by Jas. N. Warrington, M. E.

In Part I. of the paper, the writer aims to present the most advanced views on the subject, with reliable formulæ for design. Remarks on the propeller with guide-blades.

Part II. discusses the problem: given a vessel with a certain resistance; required the most efficient instrument of propulsion. Comparison between the efficiencies of the guide-blade propeller and the common wheel. An original mathematical scheme for the design of a propeller, with a discussion of efficiency.

Improvements in apparatus for testing boilers.

NOVEMBER, 1883. Technical Training: an address delivered before the Alumni Association of Lehigh University, by Thomas M. Drown.

"The principal work of a technical school should be the training of young men in accurate habits of thinking and working. Without this training, the graduate is slow to adapt himself to new situations. The student who has been put through a routine course of study, abounding in the use of text-books, and in the solving of many problems, may be fairly informed as to the condition of his profession, and may have acquired good habits of study, and yet be unfit for practical work which involves principles which he has not learned.

"The proper training cannot be given in the class-room, but must be obtained in the laboratories.

"The centre around which should cluster all the teachings of a technical school should be physical and chemical laboratories; and the ruling idea of the school should be experiment and research. The time has fully come for technical schools to take this advanced position in the scientific training of engineers and metallurgists. The development of this school out of the shop has been so gradual that it is somewhat difficult to realize that the differentiation is now complete, and that the methods adapted for industrial schools do not fit the professional school. . . . . A great difficulty in teaching a growing science is that what is taught to-day may be obsolete to-morrow. A system of teaching should, therefore, be adopted which shall recognize this growth and be adapted to it; but we need not render unstable the attitude of a student by showing him that the ground on which he stands moves, and that he will be left behind if he does not move with it."

Apparatus for measuring carbon in steel.

A description of an apparatus, giving accurate methods for the estimation of carbon in steel, by Addison B. Clemence.

DECEMBER, 1883. The Cheapest Point of Cut-off, by Prof. Wm. D. Marks.

Experiments upon non-conducting coverings for steam pipes, by Prof. John M. Ordway.

An investigation into the efficiency of the various coverings used to prevent the radiation of heat from steam-pipes. Over fifty different coverings were tested, and the results show that simple hair-felt with a cover of cheap burlap proved the most efficient. It also appeared that, of the whole number tried, seventeen owed their efficiency to the hair. Asbestos is commonly supposed to have wonderful virtue in resisting heat, but it is a non-conductor only when it is in a light, downy condition and full of air. The experiments with hard-pressed asbestos paper show that it conducts heat very readily, and, in cases where asbestos paper was placed between the pipe and the hair-felt, the asbestos failed to prevent the scorching of the hair.

Pressures Attainable by the Use of the Drop Press, by Robert H. Thurston.

A paper read before the American Society of Mechanical Engineers on the magnitude of the pressures attainable in the use of the "drop press," employed in the process of "drop" forging, in the manufacture of small parts of firearms and light machinery.

A New Valve-Motion, by Carl Angstrom.

This valve-motion belongs to the same type as those of Brown, Marshall, and Joy, known by the name of "radial valve-motions." In a radial valve-motion, the motion is usually accomplished by an arm, two points of which move in different curves. One point moves in a closed curve, such as a circle or an ellipse, the motion being derived from an eccentric crank, or from the connecting-rod. The other point moves in either an open or a closed curve, and the motion is accomplished either by levers or slides, or by both combined. In the valve-motion under discussion, the chief distinguishing peculiarity is the mechanism for giving motion to the last-mentioned point of the valve-actuating arm.

JANUARY, 1884. Note on the losses per horse-power per hour, by condensation of the steam in pipes and cylinders of steam engines, by Professor Wm. D. Marks.

Water-line Defence and Gun-Shields for Cruisers, by P. A. Engineer N. B. Clark, U. S. N.

This paper, originally published in Vol. IX., No. V., Proceedings of the United States Naval Institute, has been revised and enlarged by the author, to correct certain statements made by Lieutenant Very (in "The Development of Armor for Naval Use") in regard to the curved shield, which statements are claimed to be erroneous.

Economy of the Compound Engine, by Professor Wm. D. Marks.

JOURNAL OF THE MILITARY SERVICE INSTITUTION OF THE UNITED STATES.

VOL. IV., NO. XVI., DECEMBER. How Early Did War Become an Art? By Captain R. M. Potter, U. S. A.

JOURNAL OF THE ROYAL UNITED SERVICE INSTITUTION.

NO. CXXI. On masting of ships-of-war, and the necessity of still employing sail-power in ocean-going ships.

In this paper, Captain G. H. Noel, R. N., argues in favor of masted vessels as being more able to make extended cruises, and to perform the various duties of fighting ships, than the mastless vessels that form part of the naval force of England. Several improvements in the rigs of vessels are suggested : steel telescopic masts ; steel tops and crosstrees ; cap backstays, coming down amidships, instead of the ordinary backstays ; slinging lower yards to saddles working horizontally on the lower masts—these last two improvements allowing sharper bracing of the lower yards.

Machine-Guns, by Captain Lord Charles Beresford, R. N.

Containing a description of the relative merits of different machine-guns. The great value of the machine shell-gun. French capture of Sfax. Tables are given containing the number of Nordenfeldt and Hotchkiss guns in use in the naval services of the principal powers of the world.

MÉMOIRES DE LA SOCIÉTÉ DES INGÉNIEURS CIVILS.

JULY, 1883. Note on the Interior Sea (Tunis), by M. A. Hauet.

Two commissions have had this subject under consideration ; one, an official board composed of senators, deputies, naval officers, diplomats, financiers, civil and military engineers ; the other, self-constituted, composed of projectors and civil engineers. The official commission is of the opinion "that there is not sufficient reason to justify the French government in encouraging the enterprise."

M. Hauet argues at length against the feasibility and propriety of the scheme of attempting to create an inland sea, as proposed by the second commission.

MITTHEILUNGEN A. D. GEBIETE D. SEEWESENS.

VOL. XI., Nos.VII.,VIII., 1883. Hotchkiss and Nordenfeldt guns, by J. Schwarz, Austrian Marine Artillery.

Describing the changes and additions made during the past year ; with tables, giving weights of guns, projectiles, charges, initial velocity, force of impact, etc.

Kapeller's Deep-Sea Thermometer, by Professors Wolf and Luksch.

The reservoir of mercury is protected from bathic pressures by a vessel of mercury surrounded by a layer of copper filings. Between four and five minutes is given as the time required for the thermometer to give a reliable reading. Other deep-sea thermometers require as much as twelve minutes.

Description, with plates, of boat-rigs in the Netherlands navy. The methods of determining the time of true noon, by equal altitudes of the sun, in the 18th century. New ships for the Brazilian navy. Launch of the Chilian cruiser Esmeralda. The Haytian navy. Deep-sea soundings (U. S. S. Enterprise, Commander Barker).

A list of fifty-three soundings between Cape de Verde and the Cape of Good Hope.

Project for the erection of lights and electric signal stations in mid-ocean.

VOL. XI., Nos. IX., X. Tables for the reduction of observations of wave-flow, by Professors Luksch and Wolf. Return of the Austrian Arctic expedition from Jan Mayen Land.

An account of the wintering on Jan Mayen, from July, 1882, to July, 1883. The station was one of those provided for by the International Polar Com-

mission. Interesting details are given of the climatic and meteorological conditions of the island.

Howaldt's plate-bending machine. Coast defence of Russia. French armored ships of the first-class. The Belleville boiler.

Vol. XI., No. XI. The position of the merchant marine in time of war. The ocean currents of the South Atlantic. The Russian use of torpedo-boats. McEvoy's one-wire system for submarine mines (trans.). Stilling waves by means of oil (trans.). Collation of observations upon the heating power and other properties of various kinds of coal. Submarine locomotion.

PROCEEDINGS OF THE INSTITUTE OF CIVIL ENGINEERS (LONDON).

1882–3, Part IV. Raising the S. S. Astral.

The Astral is the largest vessel of the Orient Steam Navigation Company's line of steamers trading between London and Australia. Her dimensions are: length 455 ft., breadth 48 ft., depth of hold 37 ft., gross tonnage 5588.

The Astral while coaling in Neutral Bay, Port Jackson, Sydney, filled and sank. Her lower coal-ports were open, and she was taking in coal on the starboard side; the water ballast, provided for ensuring stability at such times, had been removed from the double bottom; as the coaling proceeded, the side of the vessel gradually went lower till some of the port-sills were brought under water, of which a great quantity poured into the hold. The Astral went down stern first in about 52 feet depth of water at the stern, and rather less forward, settling with a list of 11° to starboard. At the time of going down, 200 tons of iron and 1500 tons of coal were on board.

To raise the vessel, a coffer-dam was constructed 410 ft. long, 30 ft. deep, and furnished with a central transverse bulkhead. The coffer-dam was made on shore in completed sections, each 16 feet in length. These sections were weighted, lowered into position, and attached to the vessel by bolts passing through the side-lights. Instead of caulking, canvas was used to make water-tight joints; this was tacked on with sufficient slack to allow for contraction. The amount of canvas covering was 26,000 square feet.

Steam pumps were set to work on the 27th of February, and on the 1st of March the vessel, having risen and righted sufficiently, was taken in tow to shallow water and grounded on the top of flood-tide. As the tide ebbed, the coffer-dam was removed. Pumping was then continued, and the vessel was in due course of time trimmed preparatory to going into dock.

This method can of course be most successfully applied in comparatively sheltered situations.

Rigs of Vessels, by Captain R. B. Forbes.

In his pamphlet on the rigs of vessels, Captain Forbes gives in an entertaining manner some personal reminiscences, and argues in favor of several radical changes in the rigs of deep-water ships and coasters.

RIVISTA MARITTIMA.

October, 1883. Naval appropriations. Collisions at sea. The battle of Port Said; a story of the future (trans.). Our prospective dockyards. The new cruisers of the United States (trans.). The Chilian Navy. Sailing vessels for instruction. International rules to prevent collisions at sea.

NOVEMBER, 1883. Naval appropriations. The disasters at Ischia and Giava. Polar expedition of the Dijmphna. The battle of Port Said (continuation). Strength of the French fleet. Application of electricity on board vessels-of-war. Improvised life-buoys and life-rafts.

SCIENTIFIC PROCEEDINGS OF THE OHIO MECHANICS' INSTITUTE.

SEPTEMBER, 1883. Mechanical Notes, by Harry M. Lane. 1. Friction of slide valves. 2. The slide valve as a water relief valve. 3. Compression and cushion.

Note on the Purification of Drinking Water. By Dr. F. Roeder.

TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.

OCTOBER, 1883. Papers read at the Troy meeting. The colorimetric determination of combined carbon in steel. Roessler's method of manufacturing sulphuric acid and sulphate of copper.

TRANSACTIONS OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS.

VOL. XII., Nos. CCLXI., CCLXII. On the current-meter, showing the reason why the maximum velocity of water flowing in open channels is below the surface. With plates and diagrams.

No. CCLXIII. Paper on the rebuilding of the Monongahela bridge at Pittsburgh, Pa. With plates and diagrams.

TRANSACTIONS OF THE NORTH OF ENGLAND INSTITUTE OF MINING AND MECHANICAL ENGINEERS.

DECEMBER, 1882. The Channel tunnel.

Mr. Charles Tylden-Wright, F. G. S., after a visit to the experimental works at Dover and Saugatte, gives an interesting description of the progress made in the trial-heading, which, on the English side, has been carried 2030 yards under the sea. It is proposed to carry the tunnel through the gray chalk stratum, at a depth of not less than 150 feet below the bed of the sea; and it is confidently expected that the number of "breaks" in this stratum will be inconsiderable for the whole distance between the English and French coasts.

The tunnel can be finished in four years, at the longest (according to Sir Edward Watkin, in charge of the experimental work), and at a cost of £3,000,000.

Arguments are brought forward in favor of two tunnels, as lessening the inconvenience attendant on accidents; and the author takes ground in favor of compressed-air locomotives for hauling *débris*, and for permanent traffic.

THE UNITED SERVICE GAZETTE.

NOVEMBER 24, 1883. Liardet's detaching and attaching gear for ships' boats.

The apparatus consists of tumbling blocks in the bow and stern of the boat. "The advantages claimed by the patentee of this gear are as follows: Simplicity

and fewness of parts, there being only three in it, two of which are movable, but not accidentally detachable. *It is perfectly under the control of one man, and he the one in charge of the boat.* The gear is unhooked, and the boat detached by the letting go of a single line. It can be hooked on or detached with the greatest ease in the darkness, and, from the fewness of its parts, it is so simple that its use is obvious to every sailor." The Commissioners of the Fisheries Exhibition awarded the prize medal to the inventor as being far in advance of all other competitors.

THE UNITED SERVICE GAZETTE.

DECEMBER 15, 1883. Improvements in Appliances for Exhibiting Lights of Ships at Sea, by Mr. John Evelyn Liardet.

Mr. Liardet's system consists of the permanent, or standing lights: masthead white; lower red and green; and stern blue; and two other masthead lights, one red and one green, which are acted on entirely by the rudder. "Thus, when it is desired to show the green lights, the masthead red light is immediately shut off, and the ship will be showing her masthead white, green, lower green, and stern blue lights . . . . The masthead green light would be shut off when desired to show the port red lights, and the ship would be showing her lower permanent port red, masthead red and white lights, and stern blue light."

The light signals are effected by Mr. Liardet's system, and application of electricity.

ADDITIONS TO LIBRARY.

EXCHANGES.

American Chemical Journal, Vol. 1, No. 1, to Vol. 5, No. 5, inclusive.
Annalen der Hydrographie u. Maritimen Meteorologie. Nos. 9, 10, 11, 1883.
Bulletin of the American Iron and Steel Association. Weekly.
Bulletin de la Réunion des Officiers. Sept. 22, No. 38, to December 29, No. 52.
Giornale di Artiglieria é Genio. Part 2, Nos. 9, 10, 11, 1883.
Journal de la Flotte, Sept. 9 to Dec. 23, 1883.
Journal of the Franklin Institute, Nov., Dec., 1883, Jan., 1884.
Journal of the Military Service Institution of the United States. Dec. 1883. Vol. IV., No. XVI.
Journal of the Royal United Service Institution. Vol. XXVII., No. CXXI.
Mémoires de la Société des Ingénieurs Civils. Nos. 7, 8, 9, 10, 1883.
Mittheilungen a. d. Gebiete des Seewesens. Vol. XI., Nos. 7, 8, 9, 10, 11, 1883.
Norsk Tiddskrift for Sovaesen. Oct., Nov., Dec., 1883.
Proceedings of the Institution of Civil Engineers (London, England). Vol. LIX., Pt. I. to Vol. LXXIV., Pt. IV. 1879–83.
Proceedings of the Institution of Mechanical Engineers (London, England). No. 3, July, 1883.
Rivista Marittima. Nos. 9, 10, 11, 12, 1883.
Scientific Proceedings of the Ohio Mechanics' Institute. Vol. 2, No. 3.
Transactions of the American Institute of Mining Engineers.
Transactions of the American Society of Civil Engineers. Aug., Sept., Oct., 1883.
Transactions of the North of England Institute of Mining and Mechanical Engineers. Vol. XXXI., Pt. V., 1882, to Vol. XXXIII., Pt. I., 1883.

DONATIONS.

Problem of Interoceanic Communication by way of the American Isthmus. By John T. Sullivan, Lieutenant, U. S. N. From the Author.
Publications of the United States Artillery School, Fort Monroe, Va., embracing :
- Standing Orders for the United States Artillery School.
- Regulations and Programme of Instruction.
- Course on Military Communication. Part I., Military Bridges. By James Chester, Captain, 3d Artillery.
- Course on Military Communications. Parts II. and III., Roads and Railroads. By James Chester, Captain, 3d Artillery.
- Course of Topography. Part I., The Practical Study of Surveying Instruments. By the same author.
- Course of Sciences applied to Military Art. Part IV., Metallurgy of Iron. By Constantine Chase, 1st Lieutenant, 3d Artillery.
- Chemical Manipulations. By John P. Wisser, 1st Lieutenant, 1st Artillery.
- Artillery Exercises : Description and Service of Machine Guns. By John H. Calef, Captain, 2d Artillery.
- Course of Artillery : Ballistics. By James M. Ingalls, Captain, 1st Artillery.
- Instructions in Photography. By Lorenzo Lorain, late Major, 1st Artillery. Revised by Henry L. Harris, 1st Lieutenant, 1st Artillery.

Rigs of Vessels. By R. B. Forbes. From the Author.
The Great Admiral. A Poem. By H. L. Koopman. From the Author.

THE ESTABLISHMENT OF STEEL GUN-FACTORIES IN THE UNITED STATES.

By Lieutenant W. H. Jaques, U. S. N.,
Member of the Gun Foundry Board.

Vol. X., No. 4,—Whole No. 31, Proceedings of the Naval Institute, will be wholly devoted to an article by Lieutenant W. H. Jaques, U. S. N., on the Establishment of Steel Gun-Factories in the United States. The number will thus be a complete work in itself, fully illustrated, and will possess peculiar interest at the present time, the subject being one of paramount importance.

It is expected that No. 31, Proceedings of the Naval Institute, will be ready for issue early in May.

Orders should be sent to the Secretary, U. S. Naval Institute, Annapolis, Md.

Paper Covered, $2.00. Bound in Cloth, $2.25.

This Paper will present the report of the Board selected for the purpose of reporting to Congress what method should be adopted for the manufacture of heavy ordnance suited to modern warfare, for the use of the Army and Navy of the United States; it will contain the discussion in the XLVII. Congress, which led to the constitution of said board; the opinions of leading artillerists and steelmakers upon the subject of providing modern ordnance, and the following, relating to steel manufacture and gun fabrication:

England.

Sources from which the armament is supplied — Royal Arsenal of Woolwich — Elswick — Armstrong guns — Hydraulic machinery — Steel furnaces — Gun tools — Steam hammers — Steel manufacturers — Vavasseur gun-carriages — Sir Joseph Whitworth's Works — Hydraulic casting — Hydraulic forging — Examples of Whitworth steel — Methods of manufacturing compound armor — Bessemer Works — Basic process — Present condition of artillery — Vavasseur gun — Gun construction — Wire construction.

France.

Sources from which the armament is supplied — Bourges — Ruelle — Trucks for transportation of heavy guns — Steel manufacturers — St. Chamond — Le Creusot — Tempering pits — Steam hammers — Heating furnaces — Terre Noire — Steel and compound armor — Present condition of artillery — Gun construction — de Bauge system — Dard system — Wire construction — Schultz system — Hotchkiss revolving cannon — Hotchkiss rapid-firing gun.

Germany.

Sources from which the armament is supplied — Spandau — Krupp's Works — Krupp system — Trucks for transportation of heavy guns — Power of the Krupp guns — Present condition of artillery — Gun construction.

Russia.

Sources from which the armament is supplied — Kama — Russian Artillery gun-factory — Aboukhoff Works — Steel manufacture — Present condition of artillery — Gun construction — Steel lining-tubes.

United States.

Sources from which the armament was supplied — Sources from which the armament is supplied — Condition of steel manufacture — Cambria Iron Company — Midvale Steel Company — Springfield Iron Company.

In General.

Machines and tools for steel plant — Machines and tools for gun-factory — Buildings — Gun tool-makers — Weight of gun forgings — Plans and descriptions of sites selected by the Gun Foundry Board for gun-factories — Estimates of cost of steel plant and gun-factories.